MARS

AS VIEWED BY MARINER 9

(NASA-SP-329) MARS AS VIEWED BY MARINER 9 N75-17270
(NASA) 279 p CSCL 03B
Unclas
00/91 10908

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
U.S.A.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

NASA SP-329

MARS

AS VIEWED BY MARINER 9

A Pictorial Presentation by
the Mariner 9 Television Team
and the Planetology Program
Principal Investigators

Scientific and Technical Information Office 1974
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Washington, D.C.

Library of Congress Catalog Card No. 73-600151
For sale by the Superintendent of Documents
U.S. Government Printing Office, Washington, D.C. 20402
Price $8.15/Stock No. 3300-00522

☆ U.S. GOVERNMENT PRINTING OFFICE: 1974 O—508-064

Foreword

In the annals of space exploration, a very particular place must be reserved for a 546-kg metal object that, tumbling and silent now, is encircling an alien planet hundreds of millions of kilometers from its native Earth. It will remain, we think, in this remote orbit for at least half a century—unless perhaps some earthbound caravel of the far future picks it up for return to a place of honor in the land of its origin. This metal object is the Mariner 9 spacecraft, a singularly responsive mechanism at the end of an exiguous electromagnetic link that performed one of the most remarkable missions in the history of planetary exploration.

From the beginning—before, in fact—it was an exceptional mission. A twin spacecraft, programmed to do half the mapping and scientific reconnaissance of the planet Mars, died at birth, a victim of launch-vehicle failure. The Mariner team, working coolly under difficult constraints, rebuilt the flight plan and orbit of Mariner 9 to accomplish as many as possible of the scientific objectives of both missions. Then, after 157 days of interplanetary flight, the spacecraft arrived at Mars and successfully entered orbit—becoming the first human artifact ever to orbit another planet—only to encounter a planetwide dust storm that was veiling the surface of Mars. Although this forced postponement of the mapping mission for many weeks, it did provide an excellent opportunity to study the storm beneath. After the storm abated, Mariner 9 set about a mapping and scientific reconnaissance of exceptional quality and value. It photographed virtually the whole surface of the planet, sent more than 7000 images back to Earth, and relayed a total of more than 30 billion bits of information, an amount equivalent to 36 times the entire text of the *Encyclopaedia Britannica*. This is incomparably more than had been received from all earlier planetary missions together. The pictures in this volume, which is but one of many scientific reports to derive from the mission, provide in their view of canyons and giant crevasses, craters and volcanoes, a new and exciting understanding of the red planet.

James C. Fletcher, Administrator
National Aeronautics and Space Administration

Preface

Mariner 9 was launched from Kennedy Space Center on May 30, 1971. A midcourse maneuver on June 5 placed its aiming point so close to Mars that no additional course correction was necessary. The spacecraft was successfully inserted into Mars orbit on November 14 at 00:15:29 GMT, becoming the first manmade object to orbit another planet.

Initiated in 1968, the Mariner Mars 1971 Program had called for two spacecraft to orbit Mars during the 1971 opportunity, one in a high inclination orbit and the other in a low inclination orbit. After Mariner 8 was lost during launch on May 9, the operational strategy was changed to an intermediate inclination orbit to achieve maximum scientific return from a single orbiter. The objective of the mission was to explore Mars from orbit for a period of time sufficient to observe a large fraction of the surface and to examine selected areas for dynamic changes. Imagery of the surface was to be obtained as well as significant data on the atmosphere and surface characteristics.

Eleven Principal Investigators were concerned with the six experiments carried by Mariner 9:

Television—H. Masursky (team leader), U.S. Geological Survey, Flagstaff; G. Briggs, Jet Propulsion Laboratory; G. De Vaucouleurs, University of Texas; J. Lederberg, Stanford University; B. Smith, New Mexico State University.

Ultraviolet spectroscopy—C. Barth, University of Colorado.

Infrared spectroscopy—R. Hanel, NASA Goddard Space Flight Center.

Infrared radiometry—G. Neugebauer, California Institute of Technology.

S-band occultation—A. Kliore, Jet Propulsion Laboratory.

Celestial mechanics—J. Lorell (team leader), Jet Propulsion Laboratory; I. Shapiro, Massachusetts Institute of Technology.

The spacecraft was approaching Mars, when telescopes on Earth revealed that a planetwide dust storm had broken out and was totally obscuring its surface. From November to mid-December only faint markings appeared on the surface of Mars and sometimes a diffuse feature with a series of billowing dust waves on its lee side. The last picture taken before orbital insertion had shown four curious dark spots aligned in a T-shaped pattern, and it was theorized that they might be high-standing parts of an otherwise obscured planet. This area was monitored repeatedly during the course of the storm, and as successive pictures showed more and more detail it became clear to the science team that these were the summit areas of enormous volcanoes protruding through the top of the dust cloud. By the end of December it appeared that the dust storm was diminishing and that the planetary mapping sequences could soon begin.

From January 1972 onward, every week was punctuated by new and startling discoveries. First there were the enormous volcanoes standing as much as 15 miles above the average surface, each one about the size of

Arizona. Then, totally unanticipated, immense canyons appeared, including a great equatorial chasm more than ten times the size of the U.S. Grand Canyon. The canyons proved to have eroded walls, and in addition numerous dendritic tributaries extended back from the canyon walls, suggesting that water erosion may have played a role in sculpturing the surface of Mars some time in its past. Yet it was known from previous flyby missions that atmospheric and surface temperature conditions are such as to prevent liquid water from existing in adequate quantity at the present time. For this reason the science team was astounded by the apparent evidences of erosion, and then by the discovery of non-canyon-related sinuous channels that had all the earmarks of dry river valleys. Eroded cliffs appeared, as well as wind-erosion features and large dune masses. It is difficult to convey the sense of high excitement that pervaded the scientific investigators as the newly perceived character of our sister planet began to unfold.

Soon it became apparent that almost all generalizations about Mars derived from Mariners 4, 6, and 7 would have to be modified or abandoned. The participants in earlier flyby missions had been victims of an unfortunate happenstance of timing. Each earlier spacecraft (except in part for Mariner 7, which had returned startling pictures of the south polar regions) had chanced to fly by the most lunar-like parts of the surface, returning pictures of what we now believe to be primitive, cratered areas. Given a difference of as little as six hours in arrival times of any of these earlier spacecraft (each of which had spent many months in transit), an entirely different view of Mars would have resulted. It was almost as if spacecraft from some other civilization had flown by Earth and chanced to return pictures only of its oceans.

Mars moved behind the Sun in early August 1972, and the spacecraft could no longer be commanded from Earth. At this point in the mission nearly all the planet had been mapped with the low resolution camera, and about 2 percent of its surface covered by the high resolution camera, specially targeted over points of high scientific interest. In addition, the waning of the south polar cap had been examined in detail, and the layered and pitted deposits in these regions extensively pictured. At an altitude of 1650 km the resolution of the TV camera system was about 1 km for the low resolution camera and about 100 m for the high resolution camera.

When Mars came out from behind the solar corona on October 12, so that scientific operations with the orbiter could be resumed, mapping coverage of the northern latitudes was completed and the northern polar regions examined in detail. After a lifetime in space of 516 days, the Mariner 9 spacecraft ran out of attitude-control gas and tumbled out of control on October 27, 1972, almost one year after it had been inserted into Mars orbit.—J. F. McCauley, H. F. Hipsher, and R. H. Steinbacher.

Page Intentionally Left Blank

Contents

Page		
1	1	Introduction
5	2	Giant Volcanoes of Mars
27	3	Mysterious Canyons
41	4	Channels
57	5	Fractures and Faults
71	6	Escarpments
83	7	Fretted and Chaotic Terrains
91	8	Craters
101	9	Wind-Shaped Features
113	10	Changing Features
125	11	Extensive Plains
133	12	Polar Regions
149	13	Clouds of Mars
163	14	Natural Satellites
169	15	Martian Enigmas
185	16	Similarities: Mars, Earth, and Moon
221		Availability of Photographic Prints
223		Shaded Relief Map of Mars

1
Introduction

Although the dust storm delayed the start of systematic mapping, it afforded an unparalleled opportunity to examine its effects on the surface and atmosphere of Mars. Pictures of the limb were taken showing that dust reached the enormous elevation of about 70 km (43 mi.). Gradually features emerged through the haze. At first only the dimly shining south polar cap and four dark spots could be seen. One of the dark spots had been noted during the dust storms of 1924 and 1956 by astronomers. Under normal conditions this feature appears as a bright white spot, Olympus Mons. The other three spots lay in the area where periodic brightenings called the "W-cloud" have often appeared. As the storm gradually subsided and the atmosphere cleared, the four spots turned out to be high mountains with craters at their summits. Olympus Mons appeared as an immense shield volcano 24 km high with long finger-shaped lava flows on its flanks — the largest volcanic pile ever photographed. Later a great plateau became visible, sloping to the east from the volcanoes. On it appeared a bright stripe that later turned out to be a great equatorial chasm.

The more than 7300 pictures acquired from Mariner 9 indicate that Mars is more varied and dynamic than previously inferred. Although impact craters are common, only a few small craters show continuous ejecta blankets and well developed rays. Most small craters, however, exhibit degraded, irregular ejecta blankets. About half the surface consists of ancient cratered terrain surrounding large impact basins. The largest circular feature, Hellas Planitia, is almost twice the size of the largest basin on the Moon, Mare Imbrium. Argyre Planitia is ringed by radially and concentrically textured mountainous terrain, similar to the lunar multi-ringed impact basins such as Imbrium and Orientale. The remainder of the surface is covered by younger volcanic rocks and volcanoes. These rise as much as 25 km above the mean level of extensive lava plains deposits, some of which contain windblown or possibly fluviatile deposits that are sedimentary in origin. The single volcanic edifice of Olympus Mons, which rises high above the floor of Amazonis Planitia, is almost three times the width and height of the largest of the Hawaiian volcanoes, Mauna Loa. Three other large volcanoes lie along the Tharsis ridge. The volcanoes with summit calderas have fresh flows on their slopes and appear to be relatively young. These volcanic vents provide a plausible source for much of the carbon dioxide and water in the atmosphere. The great equatorial chasm or canyon system, Valles Marineris, comparable in size to the East African Rift Valley system, is as much as 6 km deep and greater than 5000 km long, the distance from Los Angeles to New York City. It terminates in a complexly faulted plateau to the west, and in large patches of chaotic terrain to the east.

Emerging from the northern plateau lands, a complex array of broad sinuous channels descends into a regionally depressed area. Large fluvial channels begin in this chaotic terrain — possibly from episodic melting of permafrost — and seem to flow northward into the Chryse Planitia lowland. The channels merge on the border of the flat, low Chryse area; here the channel floors show

multiple braided features and streamlined islands. It has been proposed that the collapse of these rocks and formation of large-scale landslides may be caused by melting of permafrost.

Other large sinuous channels with many tributaries have no obvious sources. Small dendritic channel networks abound in the equatorial regions and imply possible rainfall. Many of the basin floors are underlain by lava flows having lobate fronts, and are inferred to be basaltic from the form of the flows, ridges, and broad, low mare-type domes that characterize their surface.

The polar regions are covered by glacio-eolian layered rocks that appear to be still forming under the present climatic regime. Older massive deposits are being eroded, pitted, and etched into troughs around the margins of the poles. Young layered deposits resembling thin laminae overlie the etch-pitted unit. The individual thin layers appear to be cyclical deposits. High velocity wind is stripping the surface and forming deflation hollows. A mantle of windblown debris, presumably derived from these circumpolar zones, thins toward the equator. These deposits smoothly blanket a subdued cratered terrain and partially fill its craters. The south and north polar regions have apparently acted as sediment or dust traps throughout much of Mars history.

Both eolian erosional features such as yardangs (wind eroded ridges) and depositional features such as dunes have been identified in the equatorial region. One dune field, about 130 km long, lies on the floor of a crater. Wind erosional and depositional processes are active, as seen by numerous changes in the albedo patterns that were monitored after the clearing of the planetwide dust storm. Redistribution of deposits of silt and clay particles reveals dark, irregular markings and light and dark tails emanating from topographic obstacles. The light tails appear to be wind-deposited material; the dark tails appear to be mostly wind-scoured zones. Throughout the mission clouds of various patterns composed of CO_2 ice crystals, water ice crystals, and local wind raised dust clouds were observed.

The temperature measurements and cloud patterns led to interpretations of the planetwide atmospheric circulation pattern, which in turn could be compared with the bright and dark surface markings that also indicate wind directions. Changes in the surface patterns were monitored on a periodic basis. During this time the dark markings that had been observed from Earth telescopes for more than a hundred years gradually reappeared after having been obscured by the storm deposits.

The retreats of both the north and south polar ice caps were observed closely. The carbon dioxide and possibly some water ice retreated by sublimation, revealing layered deposits formed by glacial-like processes, and a belt of etched pitted terrain surrounding the polar ice-cap region. The hollows may be formed by wind erosion, for the winds at the margins of the polar caps have a very high velocity on Mars, as they do on Earth in Antarctica and near the Greenland ice cap.

The spacecraft ceased functioning when it ran out of attitude-control gas after 349 days in orbital operation.

It succeeded its design lifetime by almost a factor of four, and its observations exceeded all science goals. Mariner 9 data will greatly assist planning for the Viking flights to Mars in 1975–76 that involve landing spacecraft on the surface of Mars to search for life. — H. Masursky and B. A. Smith

2
Giant Volcanoes of Mars

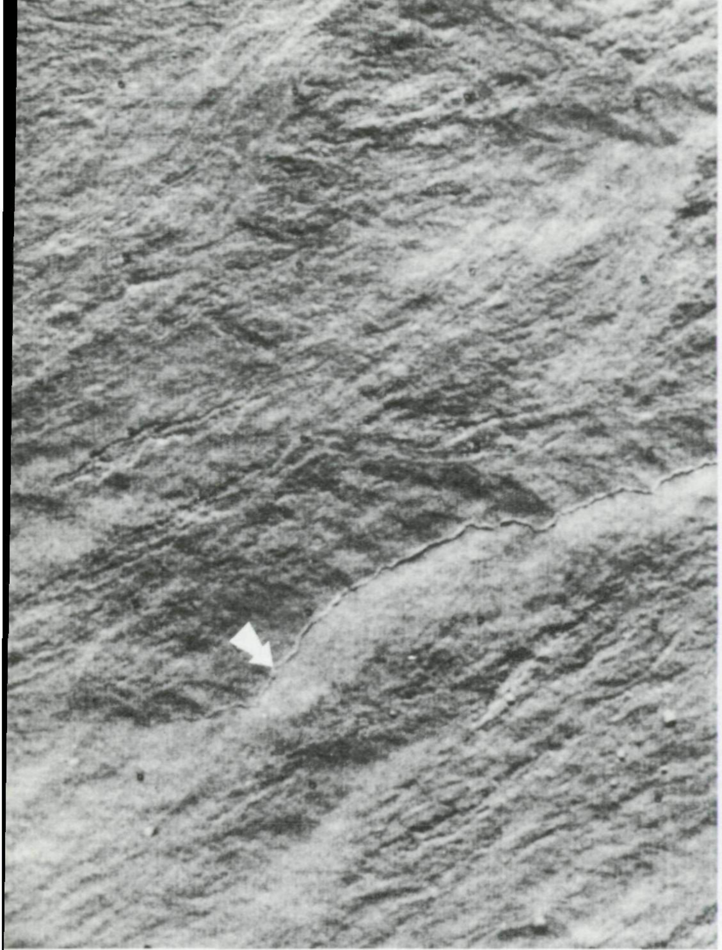
Recognition of prominent volcanic features on Mars was one of the first and most significant results of the flight of Mariner 9. During the fully developed dust storm, the only surface features clearly visible outside the polar areas were four dark spots in the Amazonis-Tharsis region. As the atmosphere cleared, those spots were seen to be the central calderas of four enormous shield volcanoes. Subsequent photography of other parts of the planet revealed more volcanic features, indicating that volcanism played a major role in the evolution of Mars. Past volcanic activity includes formation of extensive plains units, and building of the tremendous shield volcanoes and numerous smaller dome-like structures.

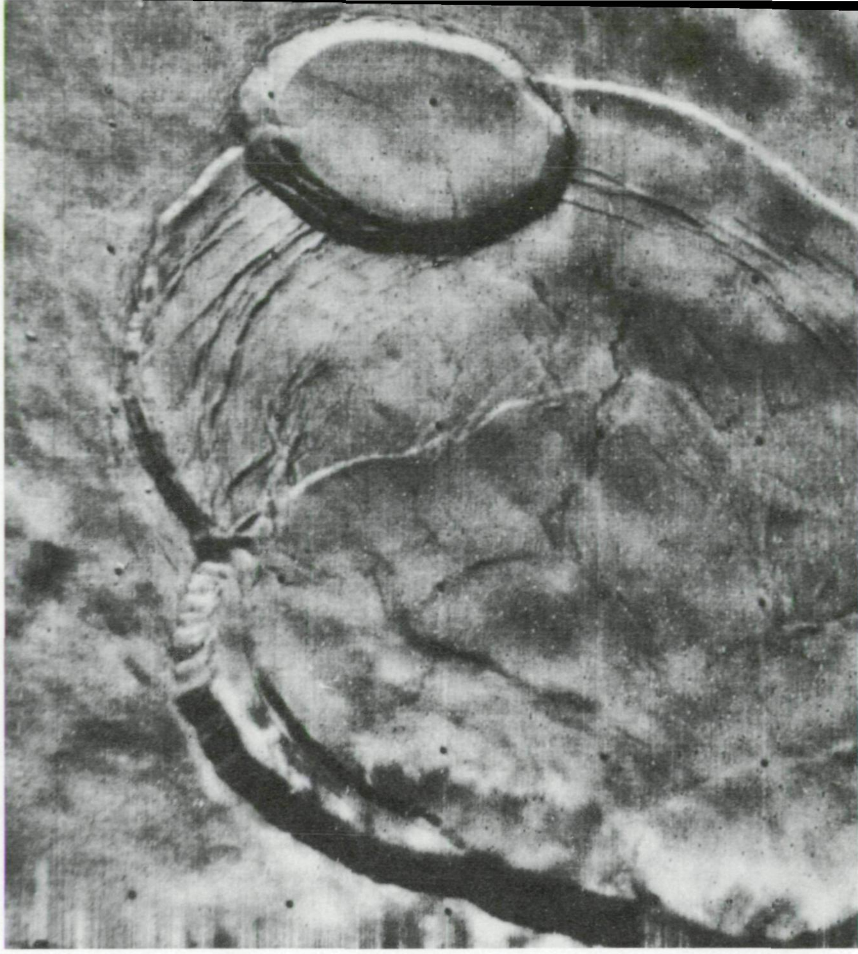
Most of the volcanic features except the plains are in the regions of high elevation. The three shield volcanoes, the Tharsis Montes, lie on a broad ridge which is 3 to 5 km above the mean level of the martian surface. Olympus Mons, the largest of the volcanic shields, lies on the western flank of this ridge. Olympus is 500 km wide and rises 29 km above the surrounding plain. The Tharsis Montes, Ascraeus, Pavonis, and Arsia Mons are each about 400 km across and, although smaller than Olympus Mons, may reach the same elevation above the mean level of Mars because of their location on a ridge. In comparison, the largest volcano on Earth, Mauna Loa in Hawaii, is approximately 200 km wide and rises about 9 km above the sea floor.

All shield volcanoes have roughly circular outlines and central summit depressions. Arsia Mons, Pavonis Mons, and an Elysium shield, Albor Tholus, have simple craters at their summits. Olympus Mons and Ascraeus Mons have complex craters as a result of successive collapses around different centers. Other volcanoes, differing from shield volcanoes in that they are smaller and simple, are properly termed domes or tholi.

The shields and domes are the most spectacular aspects of martian volcanism, but the plains on Mars may be volumetrically more significant. High resolution pictures of the plains commonly show long, low, lobate scarps (possible flow fronts) that strongly resemble features in Mare Imbrium on the Moon. By analogy with the lunar maria and terrestrial flow fronts, the plains are probably largely volcanic in origin.

In many places the cratered surface appears to be partly or wholly covered by younger plains-forming materials. In some areas only the small craters are buried, in others even the largest craters are buried entirely or show only subdued impressions. Such effects could result from eolian deposition, but volcanic activity also appears to have been widespread and products of this activity also may cover part of the cratered surface. Both volcanic plains and circular constructional features are found within the densely cratered province. Thus, although the most spectacular volcanic features occur in sparsely cratered regions, the entire planet may have been affected by volcanism. — M. H. Carr





(20°N, 135°W; MTVS 4133–96)

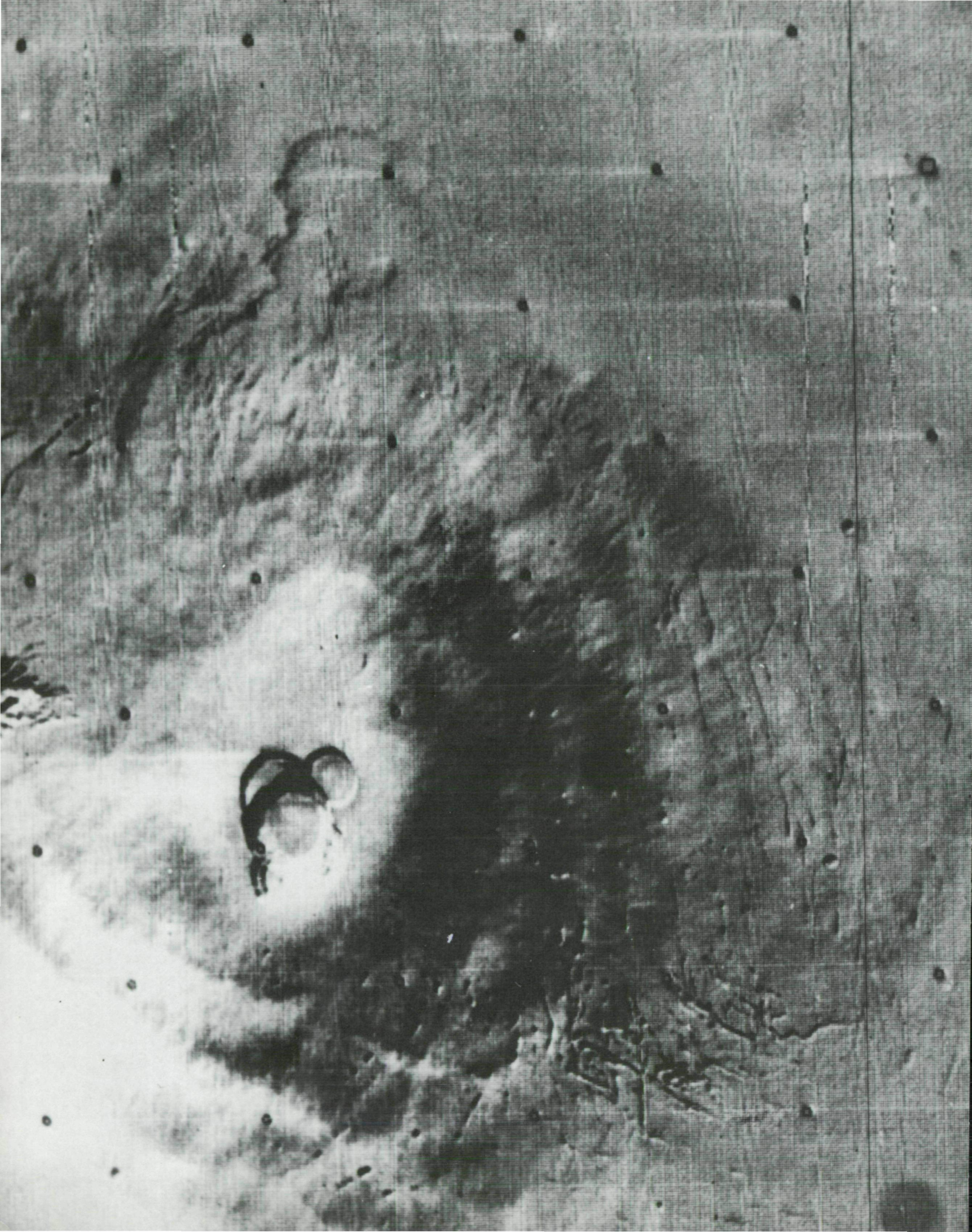
Long lava flows (above left) are visible in this photograph of the northwest flank of Olympus Mons (resolution, about 100 m). Many show natural levees such as occur along the margins of many terrestrial lava flows. The most prominent ridge has a channel (arrow) 250 m wide along 36 km of its crest that is inferred to be a lava channel. Lava flows of this form are characteristic of basaltic eruptions in the Hawaiian and Galapagos Islands on Earth.—H. Masursky

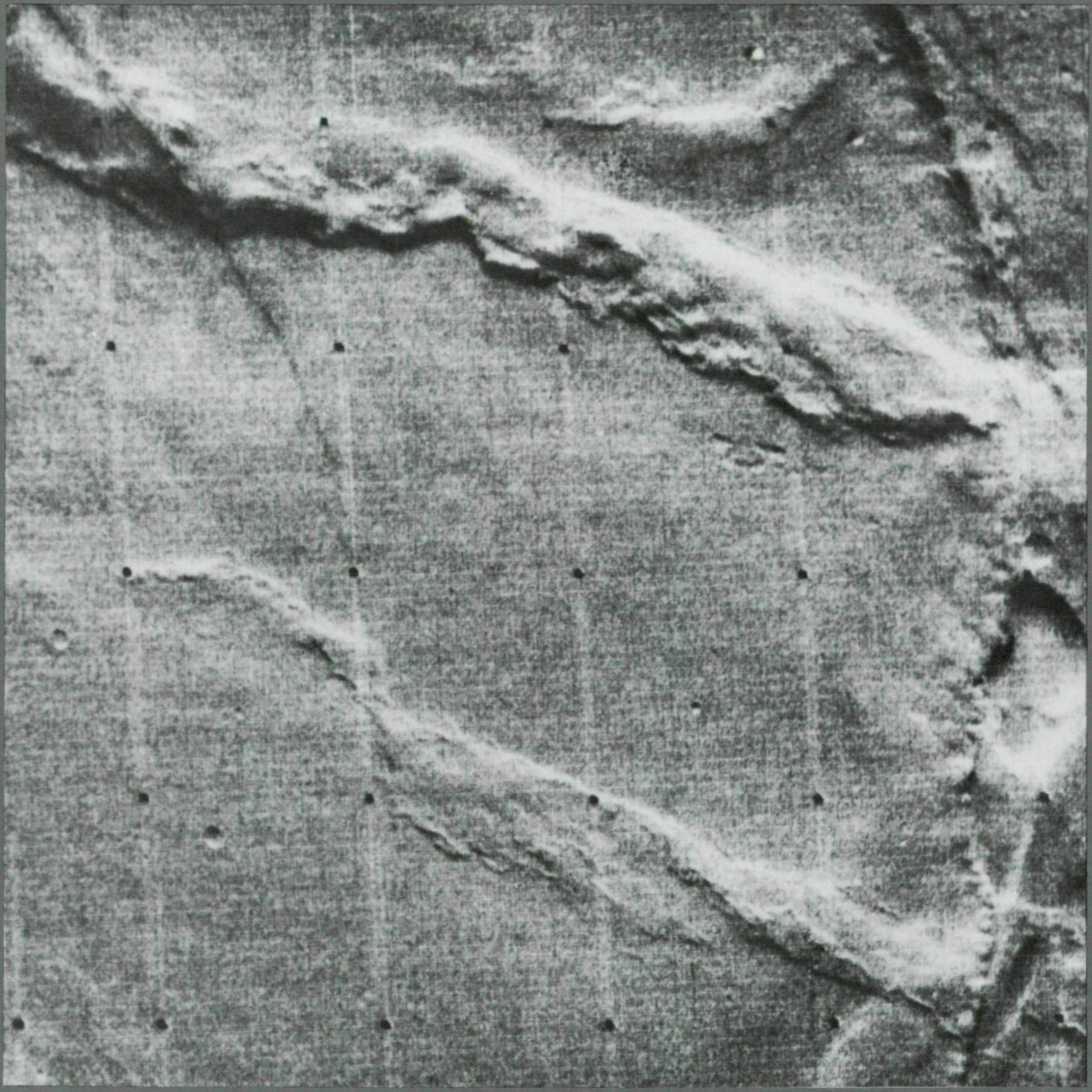
(18°N, 133°W; MTVS 4265–52)

The central caldera (above right) on Olympus Mons shows a structure of intersecting collapse depressions and concentric fractures. The inward collapse of the caldera floor is evident from the terrace pattern that steps toward the caldera center, a pattern similar to terrestrial volcanic calderas. The smaller, youngest, collapse pit (top center), is about 30 km across.—H. Masursky

(18°N, 133°W)

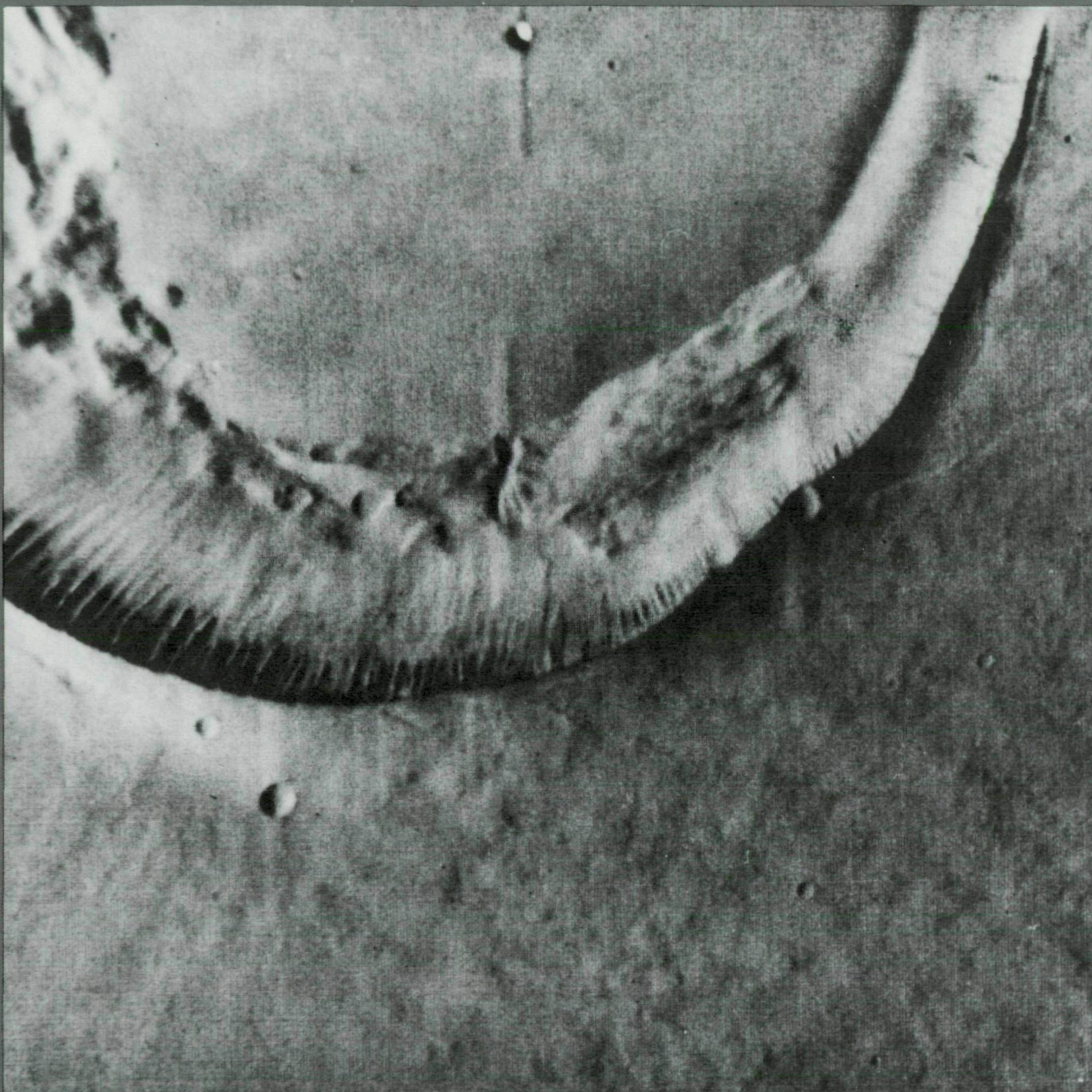
Photomosaic of Olympus Mons (facing page), the largest of the Mars volcanic mountains. The volcanic structure is 500 km across and about 29 km high, with a complex summit caldera about 70 km across. These dimensions make it the largest volcanic structure known. It is much larger than the island of Hawaii, which (on the ocean floor) at 200 km across and 9 km high is the largest volcanic pile on the Earth. The scarp around the base of Olympus Mons stands 1 to 4 km high and may have been produced by wind erosion. Originally the volcanic pile probably graded smoothly into the surrounding plain.—H. Masursky





(1°N, 113°W; IPL 7388/011543)

The ridges around Pavonis Mons are here shown enlarged, revealing their similarity to lunar maria ridges. They are inferred to be extrusions of lava along a complex fracture system extending more than 30 km down the flanks of the shield volcano. The dark patches shown in a previous picture have not yet developed.—M. H. Carr



(1°N, 113°W; MTVS 4142–93)

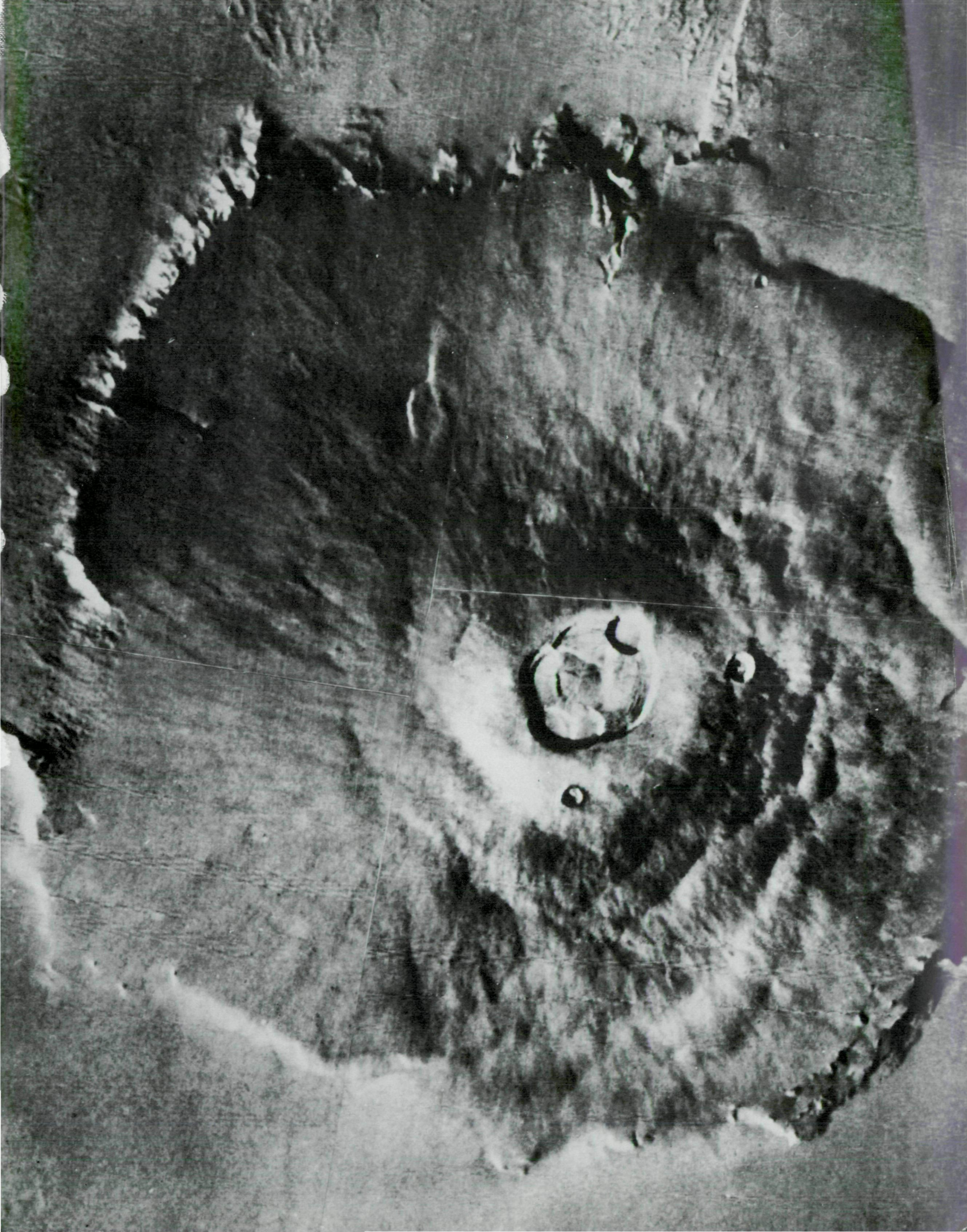
Part of the summit caldera of Pavonis Mons is shown here. The caldera-wall fluting is probably caused by debris avalanches cutting large grooves down the steep slope. Talus debris may overlie narrow terrace benches. The smooth caldera floor, which abruptly meets the steep walls, may represent the surface of a former lava lake. Well-defined impact craters with sharp rims ranging from ½ to 2 km are visible on the flanks of the volcano.—M. H. Carr

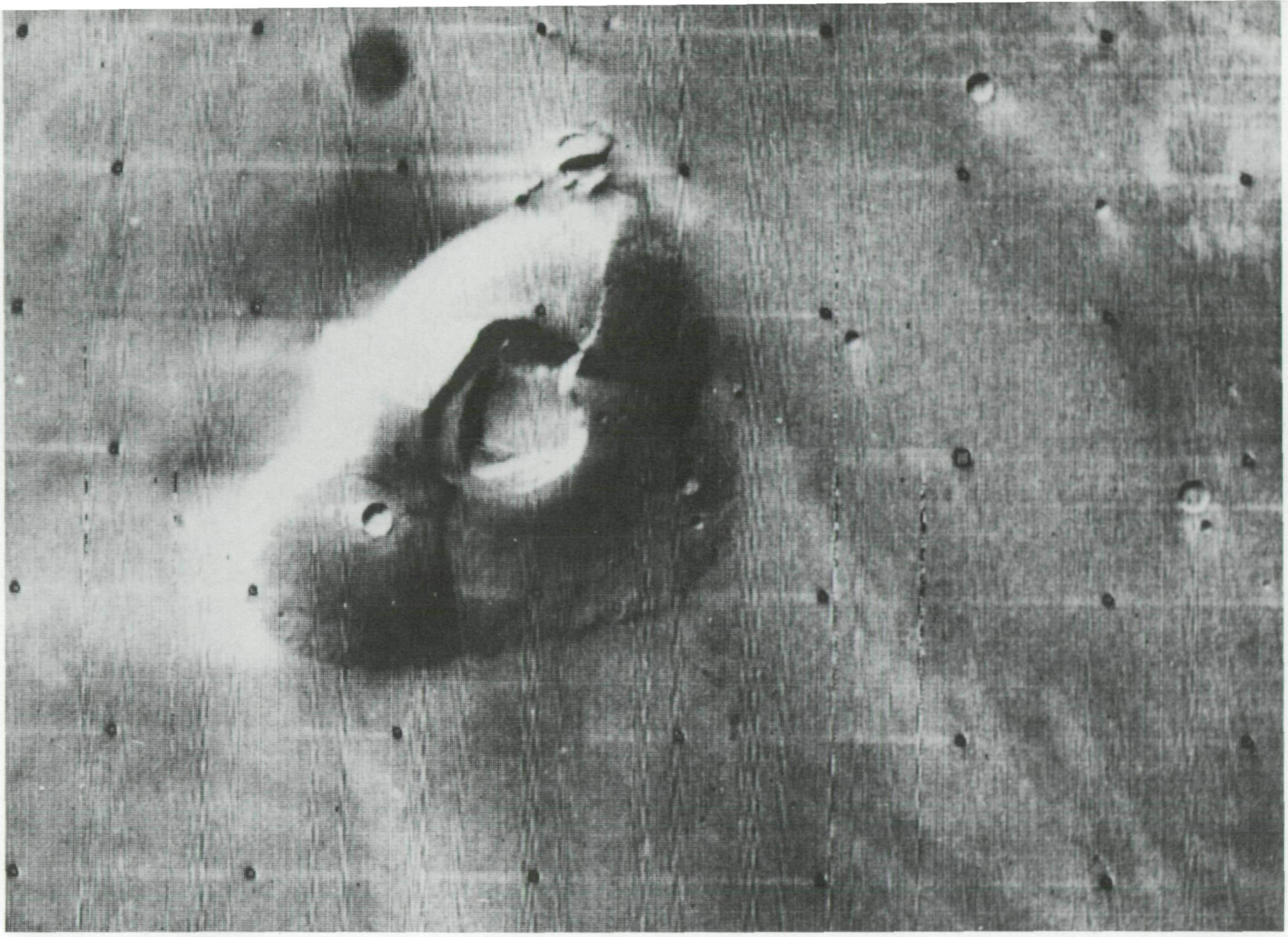
(1°N, 113°W; MTVS 4267–44)

The central crater and ring structure of Pavonis Mons are shown in this oblique view (above). The smooth crater-free floor and talus on the walls of the summit pit, and a series of collapse terraces at the sides, are clearly visible. Radial ridges, similar to lunar mare ridges, connect the central pit to the ring structure of grabens and horst ridges. The dark patches formed during the mission and were almost certainly produced by eolian processes.—M. H. Carr

(1°N, 112°W; IPL 1699/125324)

The shield volcano at Pavonis Mons (left) is about 400 km across and rises more than 20 km above the surrounding plains. Concentric graben occur on the flanks of the shield and in the surrounding plains. The caldera consists of a single large circular depression, 55 km in diameter.—M. H. Carr



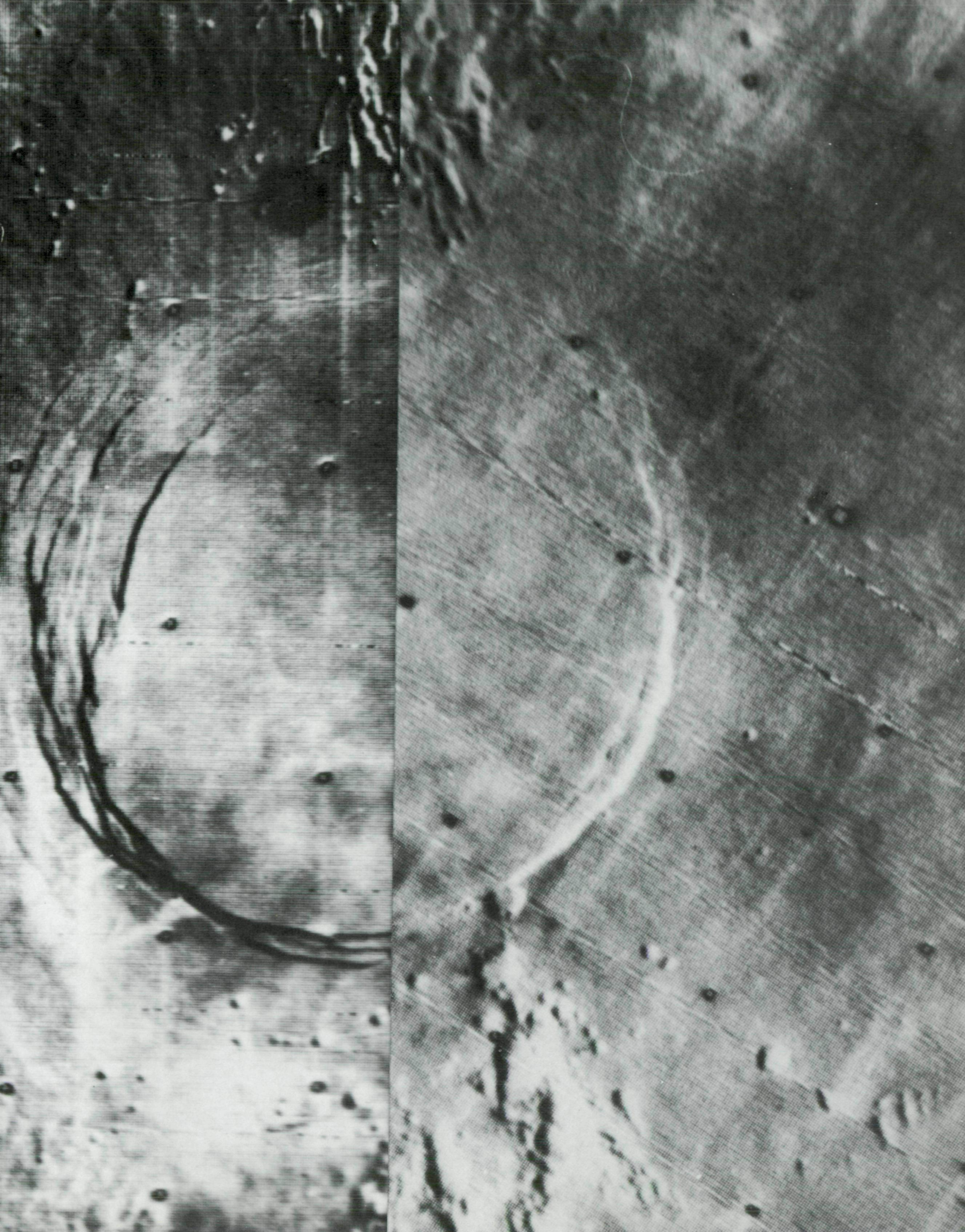


(13°N, 89°W; MTVS 4189–72)

Tharis Tholus (above), 170 km in diameter, is one of several similar volcanic domes near the Tharsis Montes. The central crater is multiple, has a flat floor and steep walls with several terraces. The flanks of the dome appear to have been faulted (upper right). Domes may form instead of the larger and more gentle shield structures when only small volumes of lava are available. Alternatively, they may indicate more viscous and possibly more siliceous lava.—M. H. Carr

(13°N, 106°W; MTVS 4184–84)

Ascraeus Mons (left), the northernmost large volcano along the crest of Tharis ridge, shows a complex summit caldera about 60 km across, the multiple overlapping craters and prominent terraces indicate the volcanic nature of the large mountains. Ascraeus Mons protruded through the planetwide dust storm as a dark spot, and in December 1972 it became the first clearly identified volcanic structure on Mars. The revelation of volcanoes on Mars thus overturned the Mariner 4, 6, and 7 thesis that Mars was a dead planet.—H. Masursky

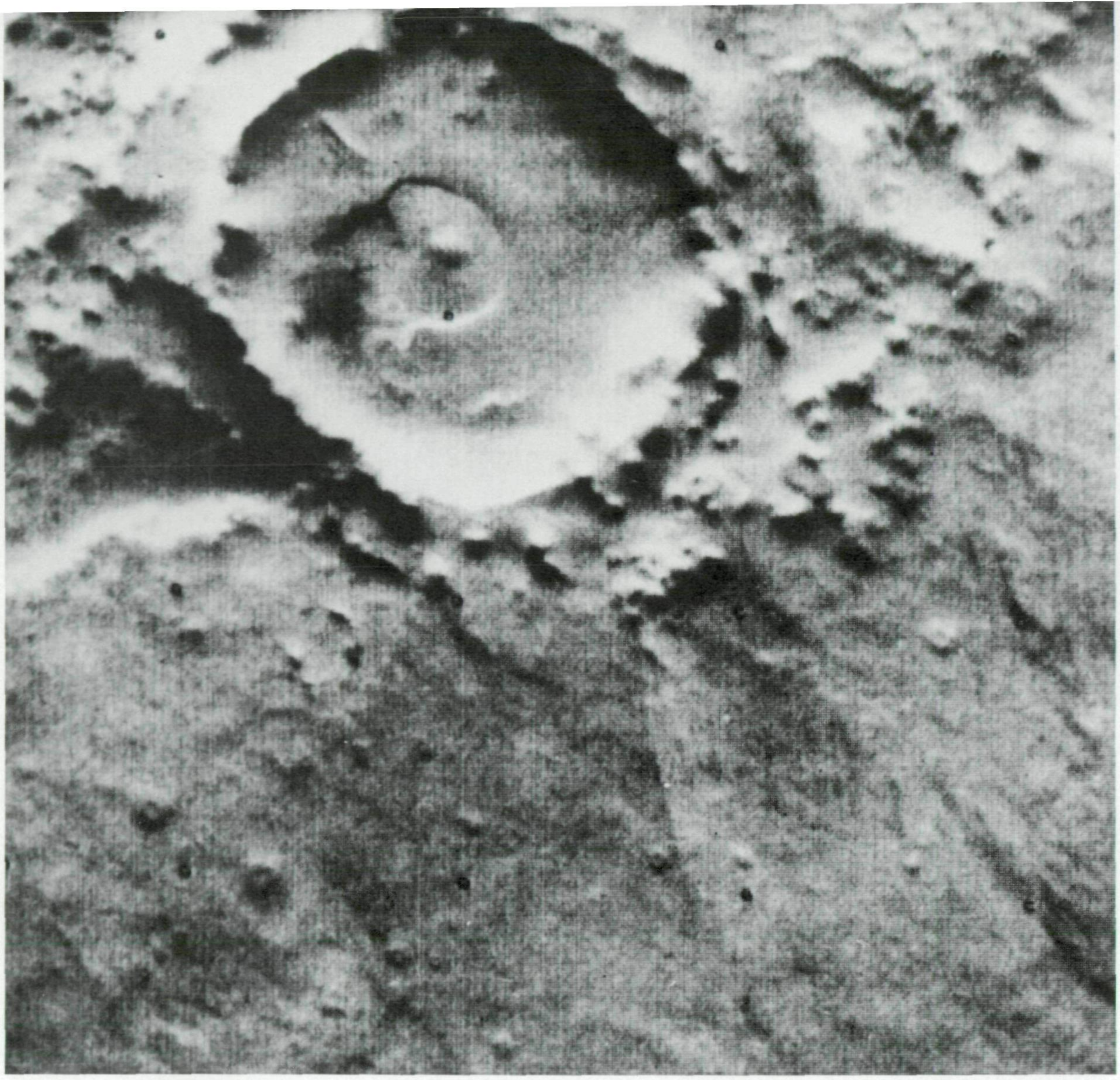


(9°S, 120°W; IPL 1633/004651, 492/141002)

Arsia Mons (preceding page): a shield volcano in the Tharsis Montes. A central smooth-floored caldera 130 km in diameter is surrounded by a zone of concentric graben. Outside the faulted zone are numerous superimposed lava-flow lobes and sinuous channels with isolated graben areas. The flanks are partly embayed by the surrounding plains materials. The structure is believed to be similar to Olympus Mons but somewhat older. The flows are shorter and thicker than those on Olympus Mons, perhaps because of chemical differences, a lower gas content, or eruption at lower temperatures. These flows are more similar to those on the flanks of Mount Rainier and Mount Hood in the Pacific Northwest of the United States that are andesitic in composition.—M. H. Carr and H. Masursky

(10°S, 124°W; MTVS 4182–42)

The southwest flank of the large volcanic shield Arsia Mons shows a rough, slightly cratered terrain with large lobate lava flows trending downslope. Wind erosion has etched the older flow fronts into a rougher terrain. The picture is about 32 km across.—T. R. McGetchin



(63°S, 323°W; MTVS 4238–7)

The crater above, 20 km in diameter, may be of impact origin with subsequent modification by volcanism. The flat-bottomed depression in its middle appears to have formed by collapse. Its central peak or dome may be a volcanic cone, as may many of the other cone-like features nearby. Surrounding the crater are many small volcanic cones, ranging from 2 km down to the limit of resolution, here around 250 m.—J. E. Peterson

(38°N, 196°W; MTVS 4244–75)

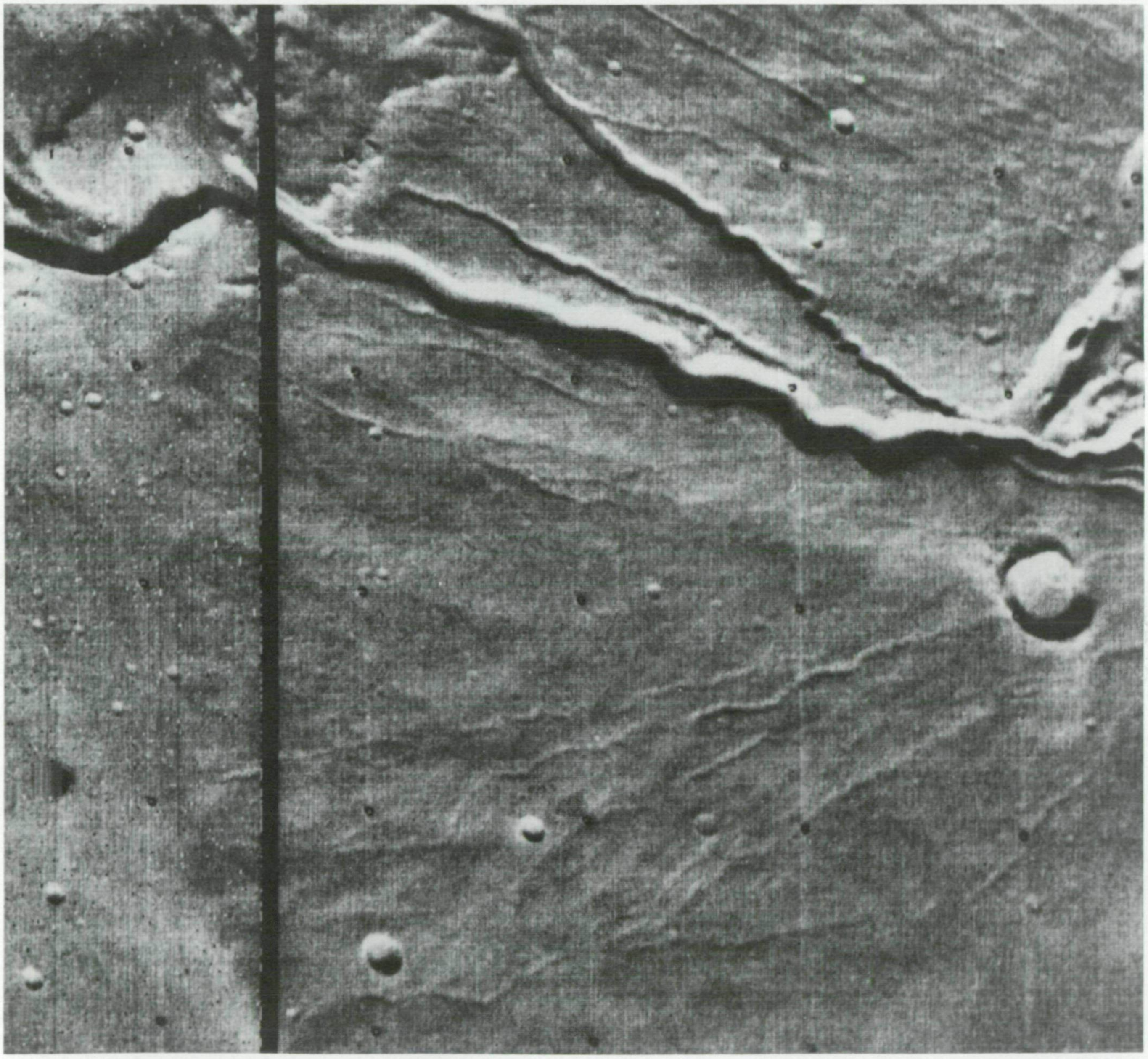
A series of small domes or volcanic cones (left) rising from a flat plains terrain. The arcuate distribution of cones suggests extrusion along the fracture system of an old crater. Note the small crater on the summit of a cone (arrow). The cones are 3 to 7 km in diameter at their bases. The intracone plain appears to consist of overlapping lava flows covered with a mantle of finer material (windblown debris or volcanic ash) which subdues the flow fronts and other relief features.—D. B. Potter

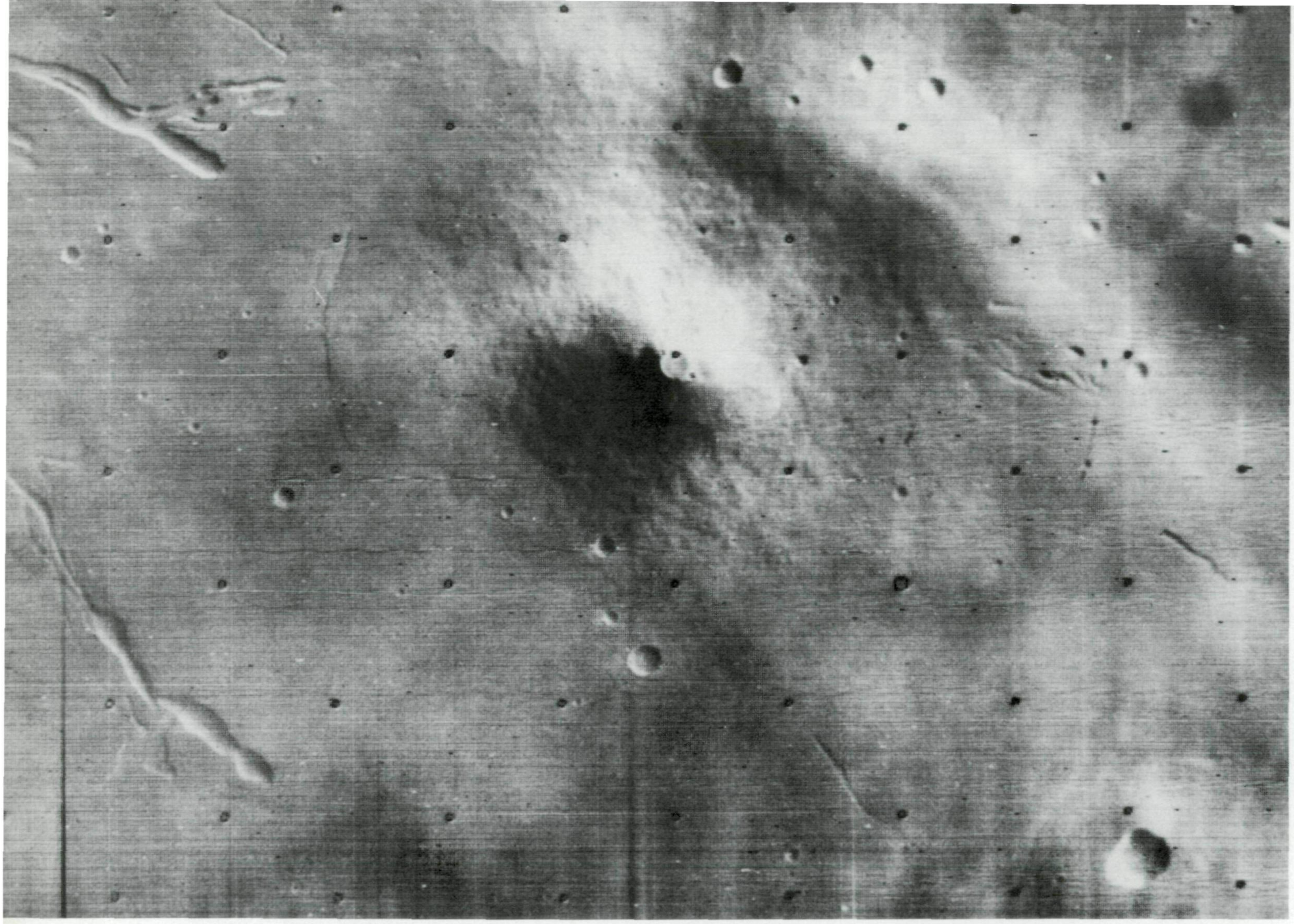
(22°N, 97°W; MTVS 4187–90)

Three volcanic domes (left) near Alba Patera. The dome of Uranius Patera (upper left) has collapsed, creating a large complex caldera. Ceraunius Tholus has a sinuous channel leading down from the caldera to a closed depression at the base of the dome. A third dome, Uranius Tholus, is seen at left center. Note the series of parallel, closely spaced fault valleys in the bottom of the photo.—D. B. Potter

(24°N, 98°W; MTVS 4271–51)

A sinuous channel, about 1 km wide, occurs on the flank of the volcanic cone Ceraunis Tholus. The summit caldera wall was breached and the channel eroded when fluids drained from the caldera basin (off right) to the closed depression at the foot of the cone. The mouth of the 40-km sinuous channel seems to grade into a deltalike deposit. Many smaller sinuous channels cross the flanks of the dome, and several channels show distributary deposits at their lower ends. Presumably, the channels are related to volcanic activity, but their overall characteristics are also similar to fluvial channels.—H. E. Holt



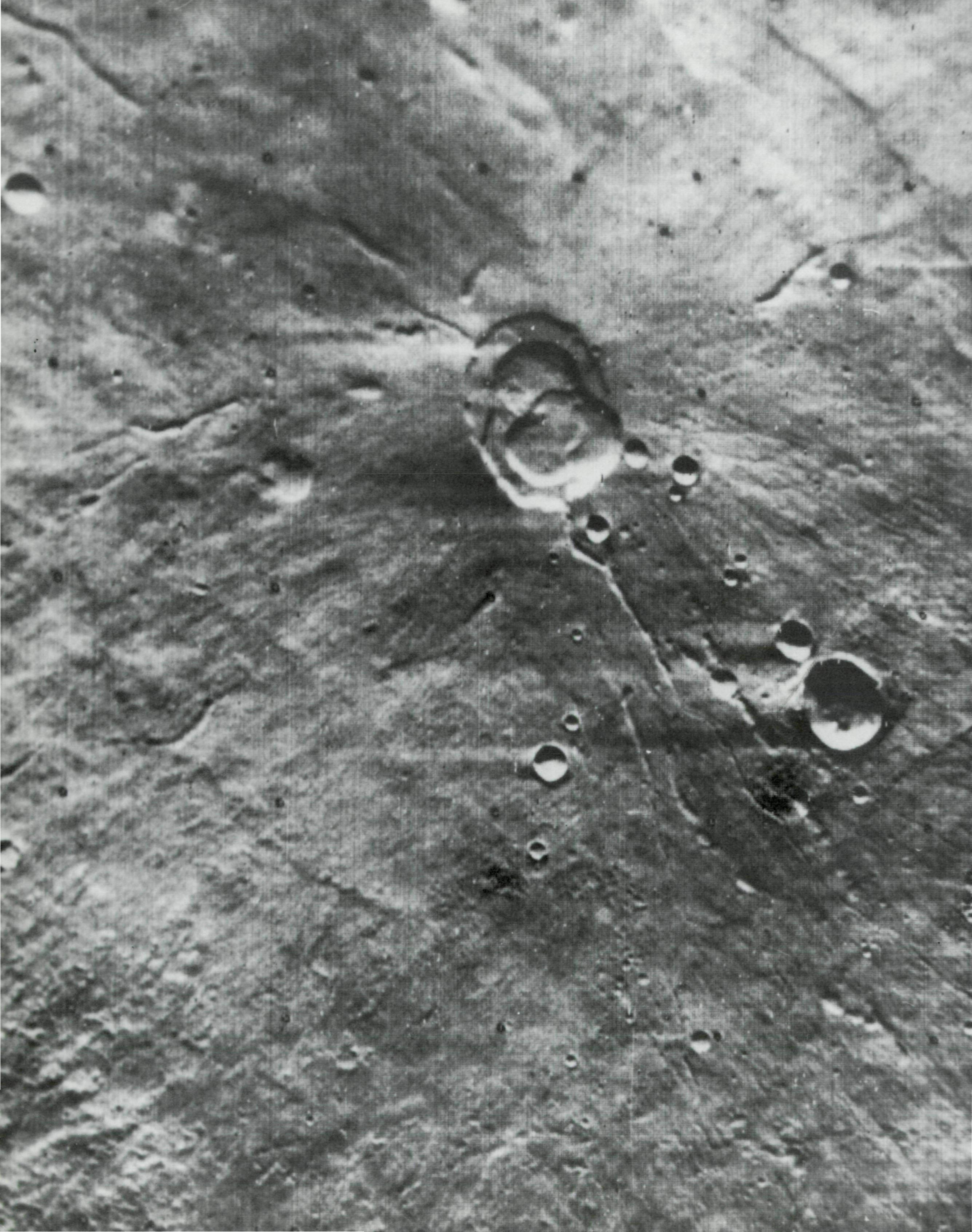


(25°N, 213°W; MTVS 4298–44)

Elysium Mons is a symmetrical shield volcano (above) approximately 225 km across, with a small central caldera and numerous fractures radial and concentric to the shield. Several channels and lines of craters in the flanks of the shield appear in high resolution photographs. Two incomplete concentric fracture rings surround the shield, one at a radius of 175 km and one at 320 km. Similar concentric fracture systems occur around other Mars shield volcanoes.—M. H. Carr

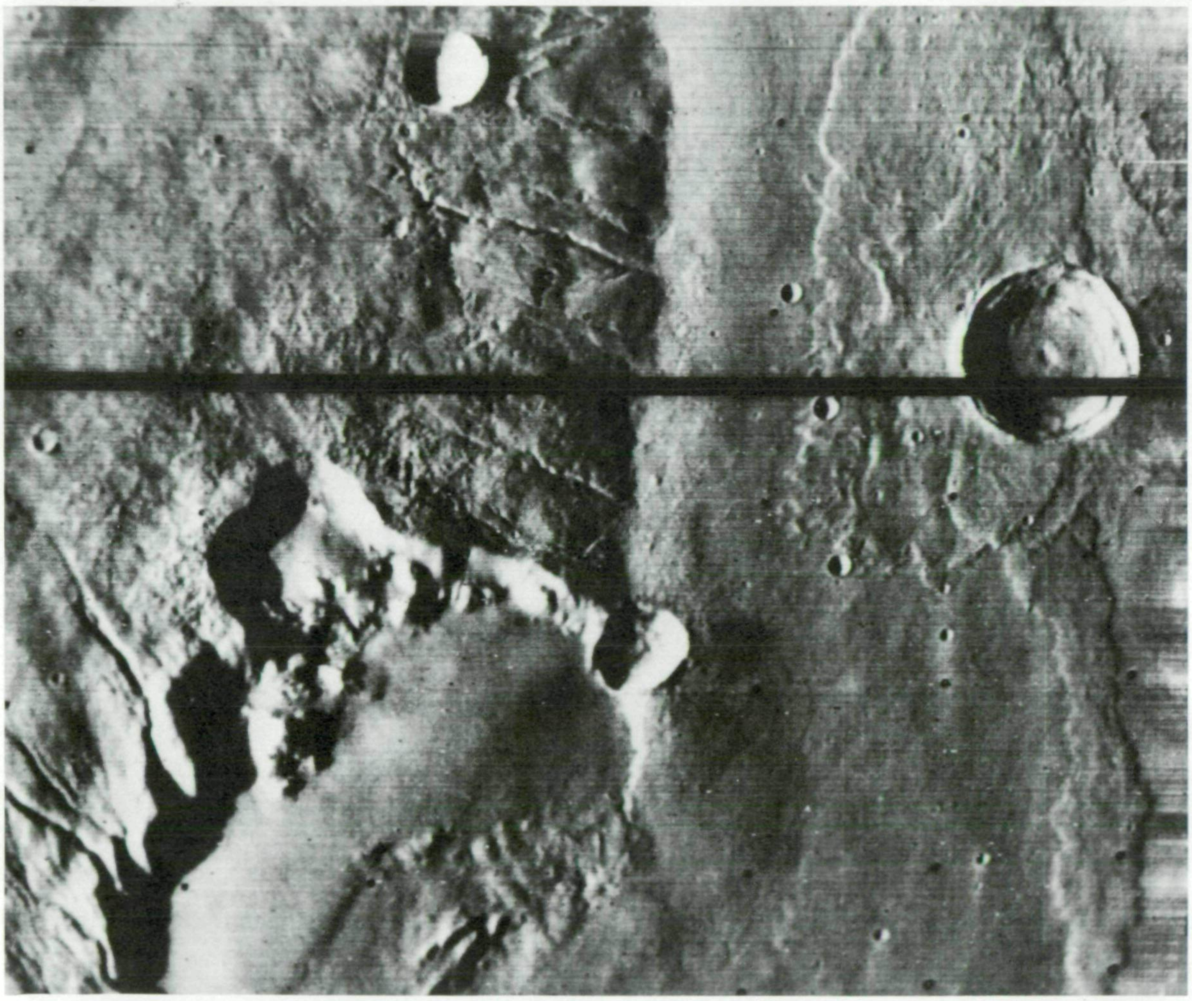
(25°N, 213°W; IPL 7386/014900, 7386/020050)

The summit area of the Elysium volcanic cone (right) shows a well defined radial pattern of material on the slopes surrounding the central crater. Several small chains of rimless pits are on the right flank of the cone. The crater rim is broken by several sinuous lava channels. The features in line with the lava channels in the lower part of the photo are possibly collapsed lava tubes. The flat floor of the crater suggests that it contained a lava lake.—J. W. Allingham



(31°N, 210°W; MTVS 4298–47)

A small caldera (left) 10 km wide on the flanks of Elysium Mons. The caldera shows multiple collapse depressions and several fine channels. Lines of small volcanic craters are arranged along radiating fractures (lower right). Like the sinuous rilles on the Moon, these lava channels start in a source crater and become narrower and shallower downslope. Terrestrial laval channels have similar forms.—H. Masursky



(32°N, 211°W; IPL 7386/023416)

The edge of the Elysium dome shows relationships that typify the contacts of volcanic domes with the surrounding plains. A low escarpment may occur as in the bottom of the frame, or the radial channels on the flanks may be truncated when they dip beneath the surrounding materials as in the upper center of the picture. Low escarpments outline a series of lobate flow sheets extending from a crater (probably volcanic) about 9 km across. The lobate flows are very similar to basaltic lava flows on the Earth and Moon.—M. H. Carr

3
Mysterious Canyons

One of the most spectacular revelations of Mariner 9 was the system of huge canyons in the equatorial region of Mars. These extraordinary features, up to 200 km wide, thousands of kilometers long, and possibly as much as 6 km deep, represent a significant phase in the planet's evolution.

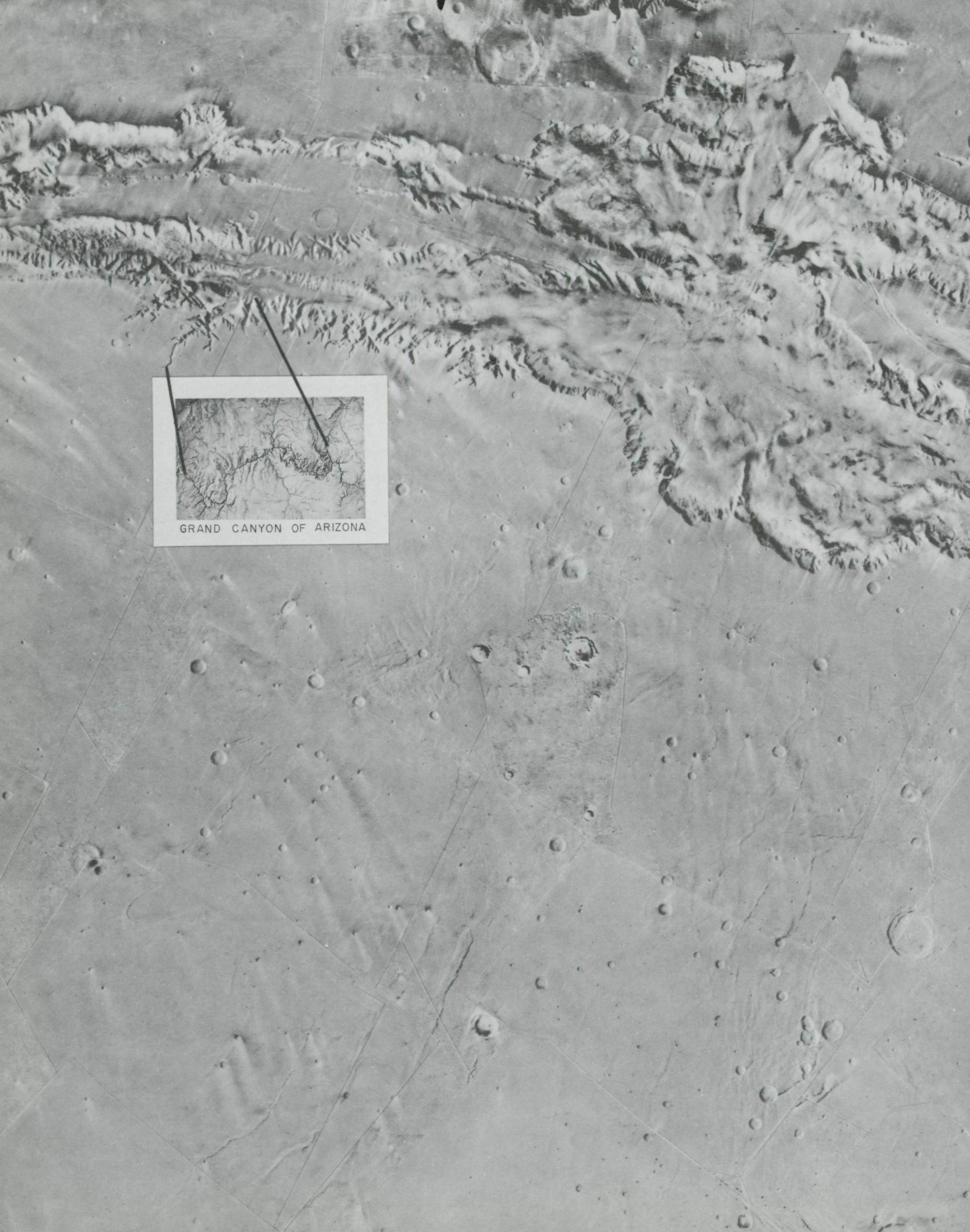
The system of canyons, Valles Marineris, extends 5000 km along the equatorial belt. Some of the dark markings that have been mapped for a century from terrestrial telescopes coincide with the floors and walls of these huge canyons. The nature of these markings remained hidden until they were pictured by Mariner 9.

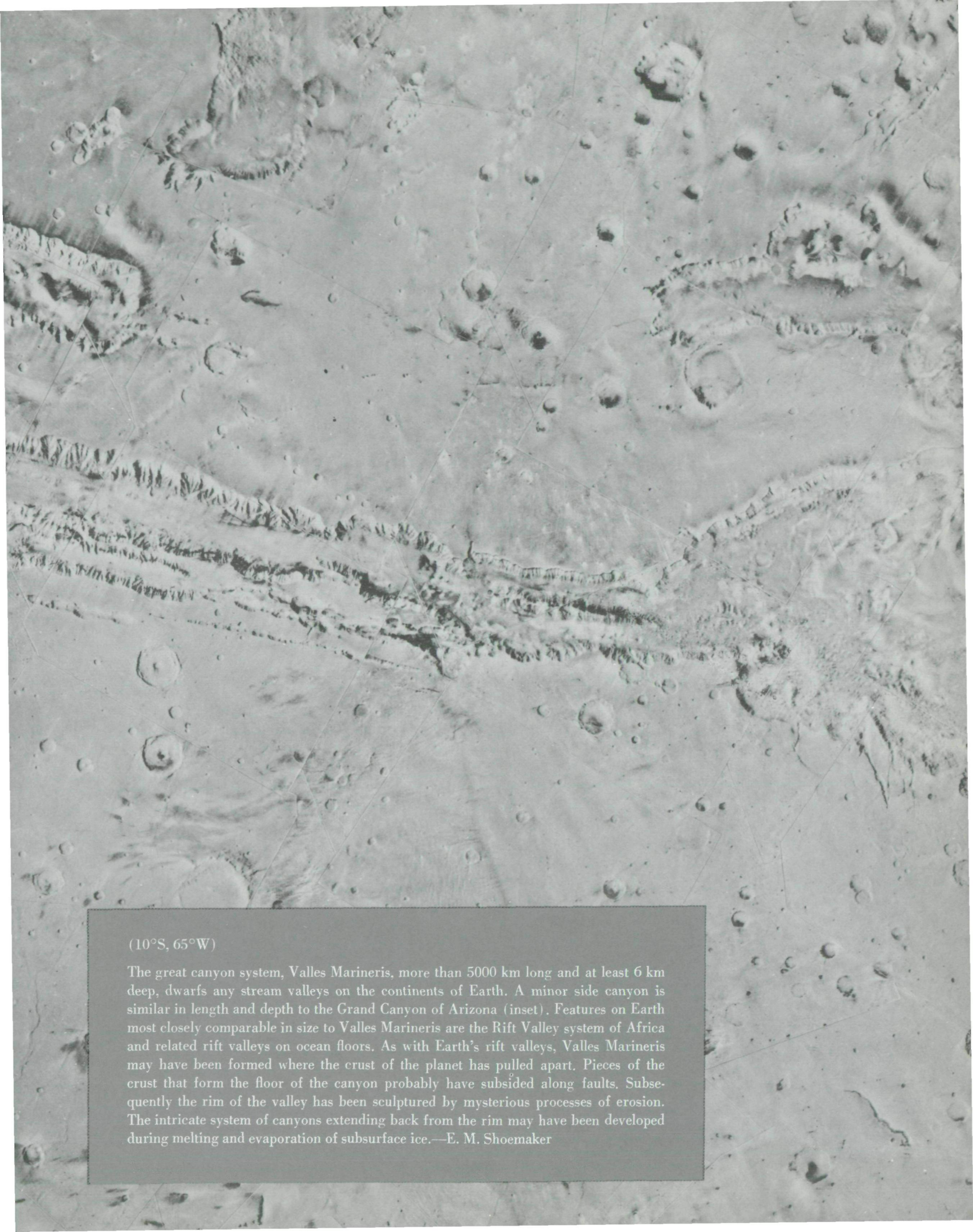
The canyons consist of a series of parallel depressions characterized by steep gullied walls and a sharp brink at the lip of each canyon. The elongation of individual depressions is parallel to the trend of the entire belt. Walls of the canyons are rarely smooth. Most of them exhibit features ranging from broad open embayments to complex branching ravines and gullies. Some of these gullies have dendritic drainage patterns and extend back into the surrounding uplands for distances of up to 150 km. Knobs, spurs, and other irregularities suggest, along with different degrees of dissection, some degree of inhomogeneity in the material forming the canyon walls themselves. The canyon floors generally lack craters, suggesting either relative youth of the floors, or the effects of some erosional process that obliterates all traces of craters.

A moderate sprinkling of craters appears on the uplands surrounding the canyons; some of these craters have broken, jumbled, and apparently downdropped floors. Another canyon-related feature is the presence of linear chains of rimless pits, probably of collapse origin. It seems that craters and pits predating the canyons have served at least partly as sites for downward collapse that lead to the formation of the small parallel canyons.

What created the canyons? The parallelism of individual canyons and the parallel trends of pit chains and smaller fault valleys or graben implies a strong degree of control by regional structural patterns. The blunt ends of the canyons suggest that the widening and lengthening of them by wall recession must have been a factor in their formation. Jumbled masses of rocky debris piled on canyon floors at the bases of numerous U-shaped gullies indicate that mass slides, slumps, and debris avalanches must have been a factor in shaping the canyon walls.

The major obstacle to any convincing explanation of the origin of the canyons is: How was the bulk of the material originally present in these enormous chasms removed? There is no obvious way to transport debris out except by wind. Yet the amount of material to be transported is so great as to cast doubt on the effectiveness of this mechanism operating by itself. The disposal of such vast amounts of material remains a problem. — J. F. McCauley


GRAND CANYON OF ARIZONA



(10°S, 65°W)

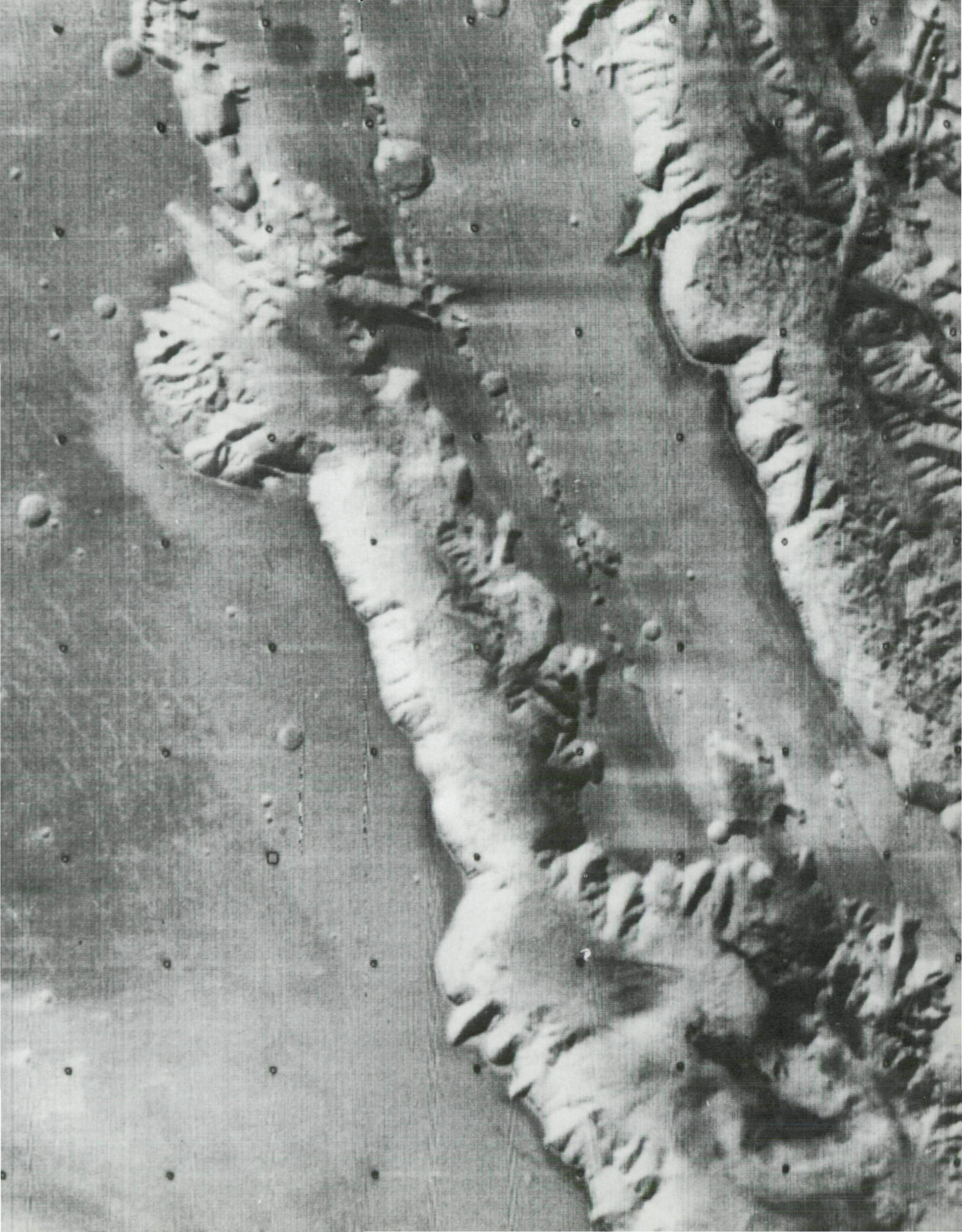
The great canyon system, Valles Marineris, more than 5000 km long and at least 6 km deep, dwarfs any stream valleys on the continents of Earth. A minor side canyon is similar in length and depth to the Grand Canyon of Arizona (inset). Features on Earth most closely comparable in size to Valles Marineris are the Rift Valley system of Africa and related rift valleys on ocean floors. As with Earth's rift valleys, Valles Marineris may have been formed where the crust of the planet has pulled apart. Pieces of the crust that form the floor of the canyon probably have subsided along faults. Subsequently the rim of the valley has been sculptured by mysterious processes of erosion. The intricate system of canyons extending back from the rim may have been developed during melting and evaporation of subsurface ice.—E. M. Shoemaker

(8°S, 84°W; MTVS 4144–87)

The spine-like ridge seen running through the center of the canyon above is located in the far canyon on the facing page. Also notable are angulate dendritic tributaries on the wall and large landslide alcoves (bottom).—R. P. Sharp

(5°S, 86°W; MTVS 4191–45)

The parallel nature (right) of elements in the canyon system is revealed by this view of two canyons with scarred and gullied walls. A chain of pits on the remnant of upland separating the two also parallels the canyons. Landslide debris is evident in the canyon floor at bottom right. The surface reflectivity variation is due to changes in the slope near the rims of the canyons. This section of canyon is 440 km long.—D. T. McClelland



(13°S, 61°W; IPL 1616/212555)

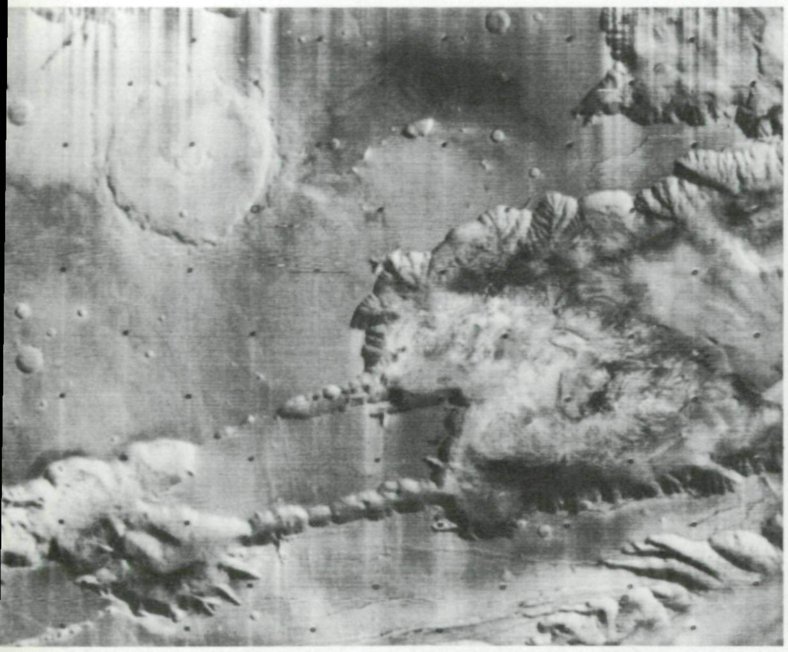
This high resolution view, about 35 km in width, of the wall of Coprates Chasma shows ravines and narrow branching divides that lie beneath a series of sharp crested alcoves. Although these features seem to resemble at first glance typical "badlands," topography of the kind produced by episodic cloudbursts in arid regions, closer inspection reveals another possible origin. The bottoms of the gullies are not interconnected and individual divides interrupt one another. Thus the pattern is not the same as that generally produced by running water but is more similar to that produced by mass wasting or gravity sliding of loose materials on oversteepened slopes.—J. F. McCauley

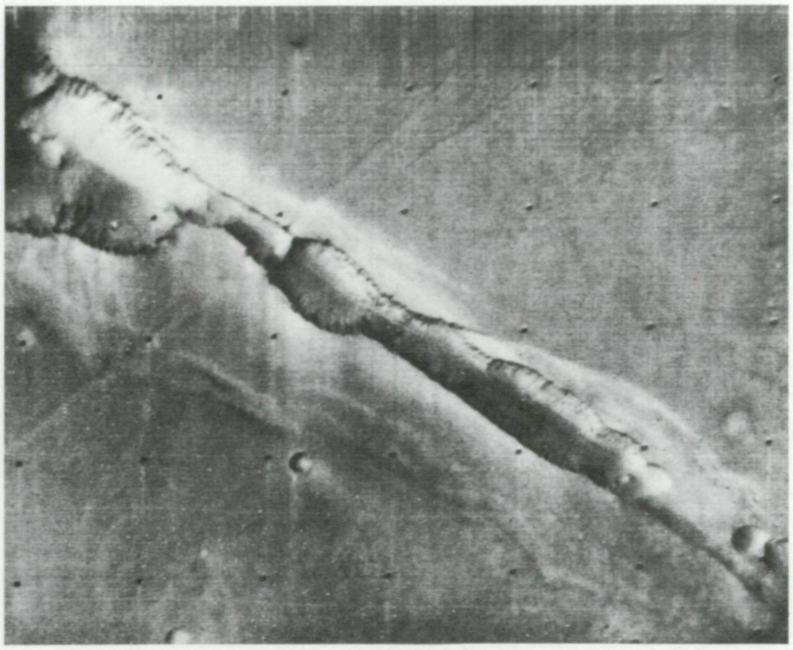
(7°S, 85°W; IPL 1354/184219)

The steep headwall, scarred by possible dry avalanche chutes at its rim, rises several kilometers above the jumbled landslide topography on the floor of the trough. The smooth band below the headwall may be accumulated talus deposits. Slides like this are locally common on trough walls. They might have resulted from undermining by removal of ground ice by evaporation or by melting under different climatic conditions. This image is about 42 km wide.—R. P. Sharp

(5°S, 77°W; IPL 1628/204400)

A blunt-ended trough (left) in Valles Marineris, Ophir Chasma, was captured in this magnificent picture, the width of which covers about 400 km. Swirl pattern on the floor of the trough may reflect outcrop of dissected floor deposits. Smaller troughs and lines of pits extending westward from the headwall suggest initiation of troughs along fractures or structures in crust.—R. P. Sharp



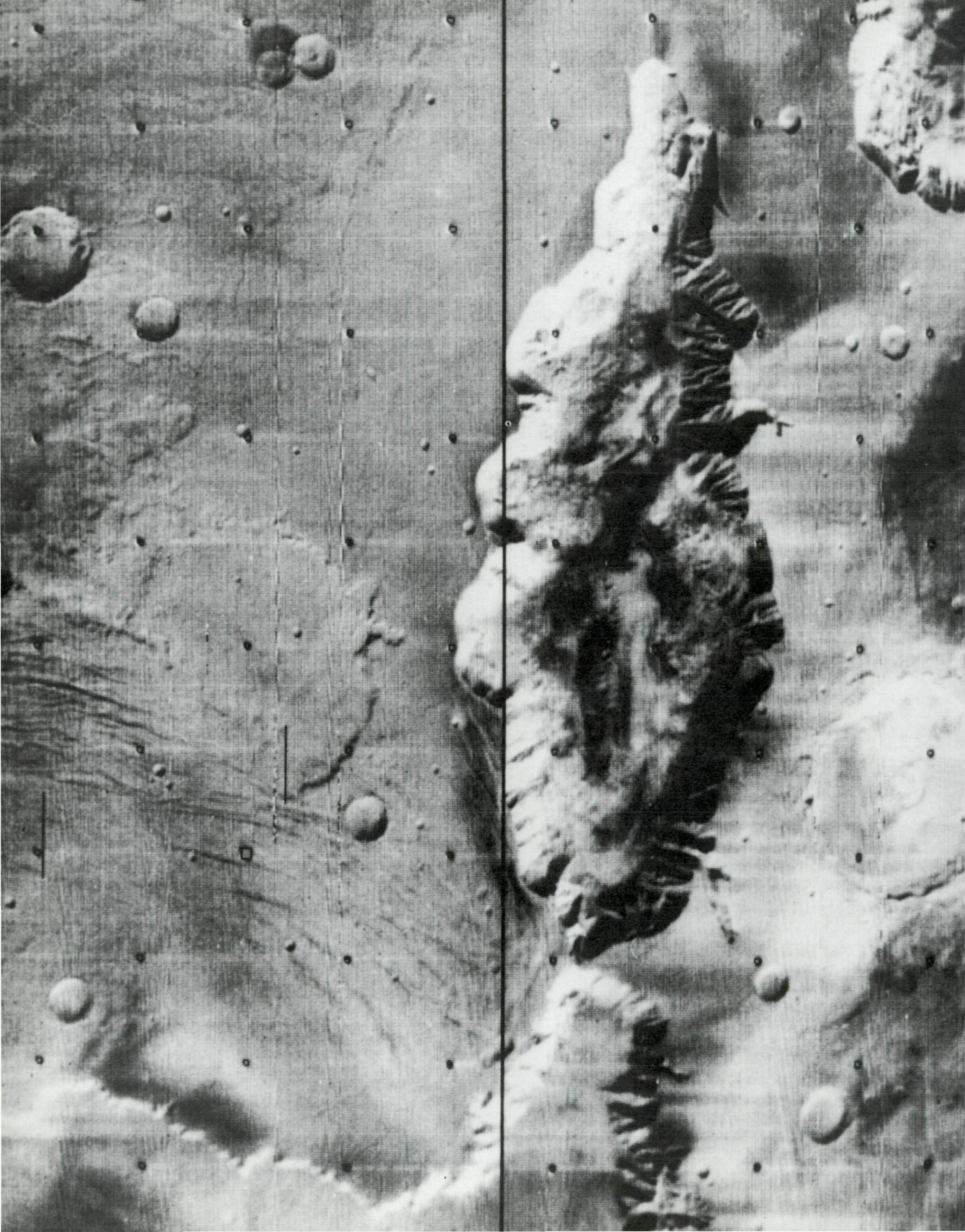


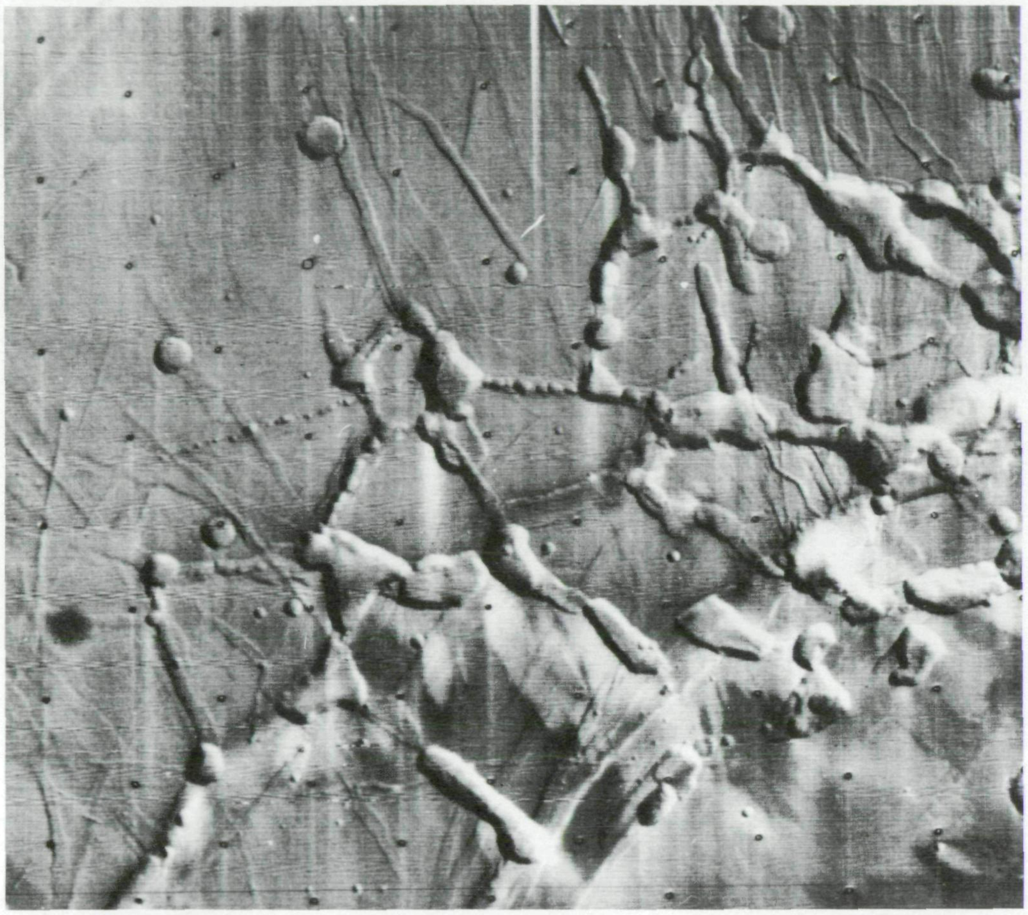
(13°S, 110°W; IPL 1348/223600)

The pits (above) at the right of this canyon suggest one possible method of enlargement of the canyons by collapse and drainage of surface material into what must be a cavernous or porous subsurface. Thus the troughs may expand along lines of these pits as well as by erosion of the walls as seen in the vertical chutes here and in the other numerous examples of wall erosion seen in this section. This picture is about 40 km in width.—J. W. Allingham

(22°S, 254°W; MTVS 4295–79)

These box canyons (right), in Hesperia Planum, display parallel trends that suggest they may have developed along fractures. They were clearly formed before the large number of local small cratering events.—D. B. Potter



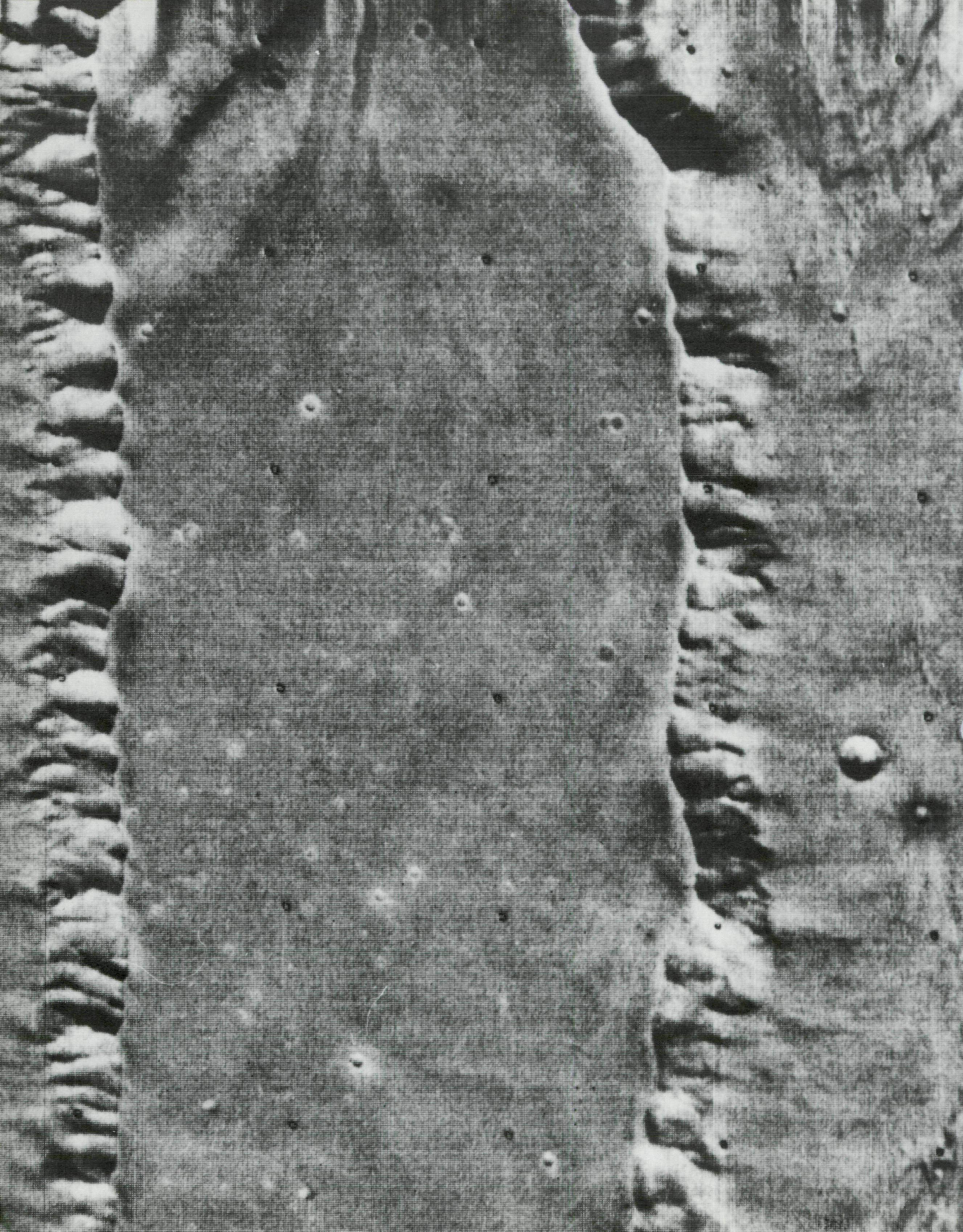


(6°S, 105°W; MTVS 4187–45)

This "labyrinth" occurs at the western end or origin of Valles Marineris as seen in this low resolution frame some 400 km across. It is characterized by smooth-walled gaping depressions and chain craters that partly surround large flat-topped mesas. Long, narrow linear graben also lace the area; many of these are cut by the steep depressions. The grossly polygonal pattern of the chain craters and elongate depressions is very reminiscent of that produced by doming on Earth but it is very much larger in scale. This region is nearly coincident with a broad swelling of the Mars surface that appears to be several kilometers higher than the surrounding plains.—J. F. McCauley

(1°S, 76°W; IPL 1628/210149)

Dead end: This 300-km-long canyon (left) is completely enclosed. It lies somewhat to the north of Coprates Chasma. Ravines and gullies mark the wall on the right while the left wall has shallow alcoves with hummocky landslide material at the base. The uplands show a range of crater size and a set of parallel fractures.—J. W. Allingham



(24°N, 62°W; IPL 1356/120125)

A mesa-like plateau occurs in the Lunae Planum region. Prominent scarps separate it from adjoining lowlands, which are shown in regional pictures as an extensive valley complex. The regular scalloping along the upper edge of the scarps suggests headward mass wasting and eolian fluting. The plateau section shown here is about 60 km in length.—T. A. Mutch

4 Channels

Numerous channels, ranging from broad sinuous channels nearly 60 km wide to small (less than 100 m wide) narrow dendritic channel networks, occur over local and widespread martian regions. Many of the channels appear remarkably similar to stream channels on Earth. Sinuous channels containing discontinuous marginal terraces, teardrop-shaped islands, and braided stream channels and bars, must have been eroded by fluids.

The channels of Mars have been grouped into four general types. Three types have characteristics that imply a fluvial origin: broad and sinuous channels, narrow channels with tributaries and braided streambeds, and closely spaced coalescent channels. A fourth variety has characteristics that imply molten lava channels.

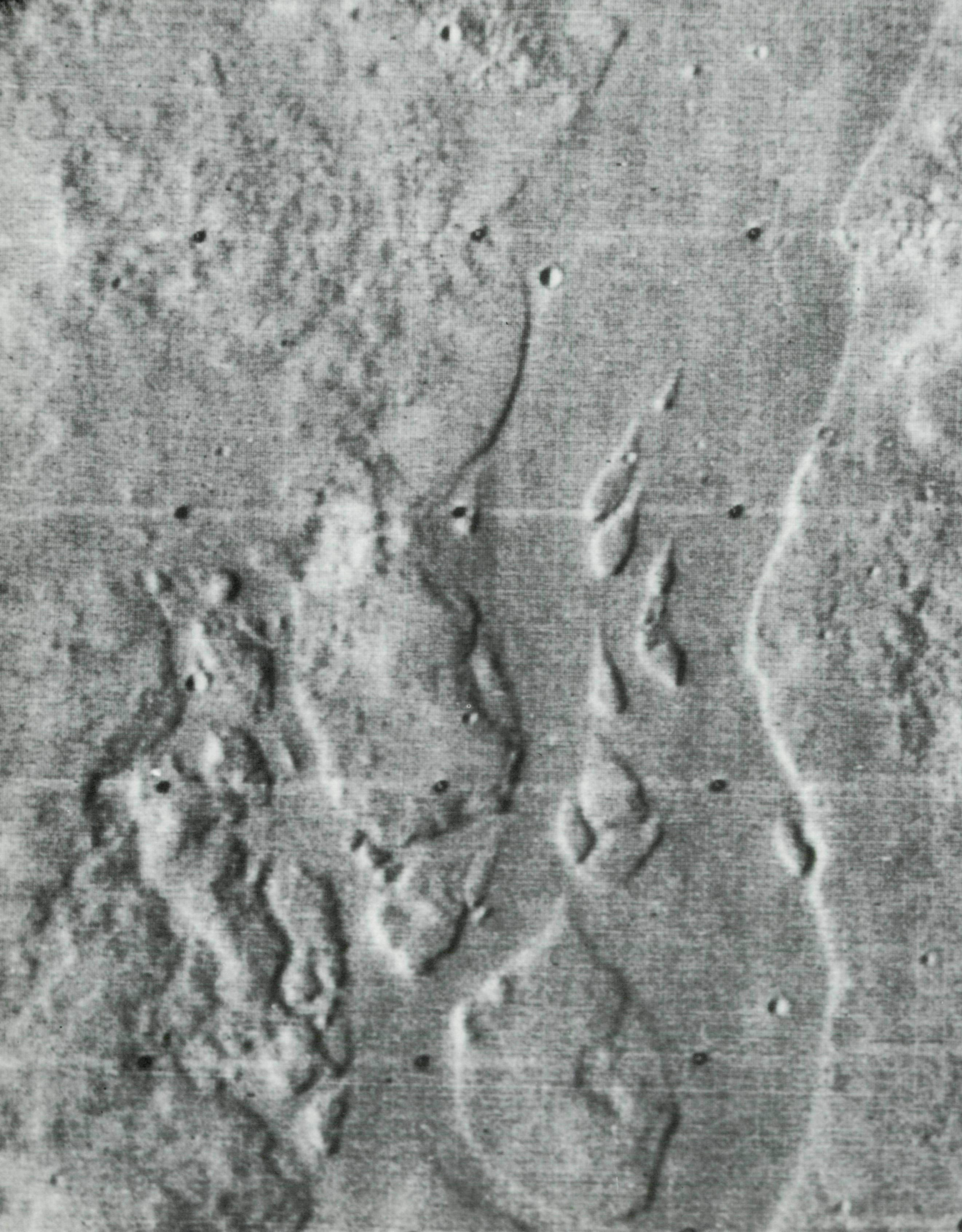
Some of the largest channels, which are 30 to 60 km wide and up to 1200 km long, appear to originate in the northern plateau lands and flow northward into the Chryse region. As the complex array of the broad, sinuous channels empties into the flat low Chryse area, the channel floors show characteristics that confirm the northward direction of flow consistent with the regional slope of the surface. These channels resemble features produced by episodic floods on Earth. The large Chryse channels have potential sources of fluids in the chaotic terrain, and the tributaries are proportional in size to the area of chaotic terrain they drain. Catastrophic melting of ground ice could form both the chaotic terrain and the giant flood channels in a single event.

Narrow, sinuous valleys, some with many tributaries forming dendritic-like patterns, lie on high level plateau surfaces such as Lunae Planum and Memnonia in the martian equatorial region. The fluvial character of these channels, combined with the lack of apparent source areas, requires the surface collection of fluids into integrated channels along with surface erosion and subsequent deposition in alluvial basins. An intermittent atmospheric source for channel erosion appears logical and is supported by the presence of channels which head very close to ridge crests.

Local networks of very small coalescent channels are widely spaced across the equatorial region. Northwest of Hellas Planitia, networks of coalescent channels run down the sides of many craters. Their form again suggests a precipitation collection system and such an origin requires widespread intermittent precipitation across the equatorial zone.

Another type of channel, associated with volcanic centers, is the lava channel or collapsed lava tube. These channels start on the flanks of volcanic domes and shield volcanoes but become less defined downslope. This relationship is the opposite of that generally observed in stream channels.

Most martian channels are indicative of past erosion, transport, and deposition of surface materials that only running water could produce. Under present martian atmospheric conditions, liquids would not exist on the surface except during rare conditions. — H. E. Holt and M. A. Sheldon



(6°S, 150°W; MTVS 4258–35, 4258–39)

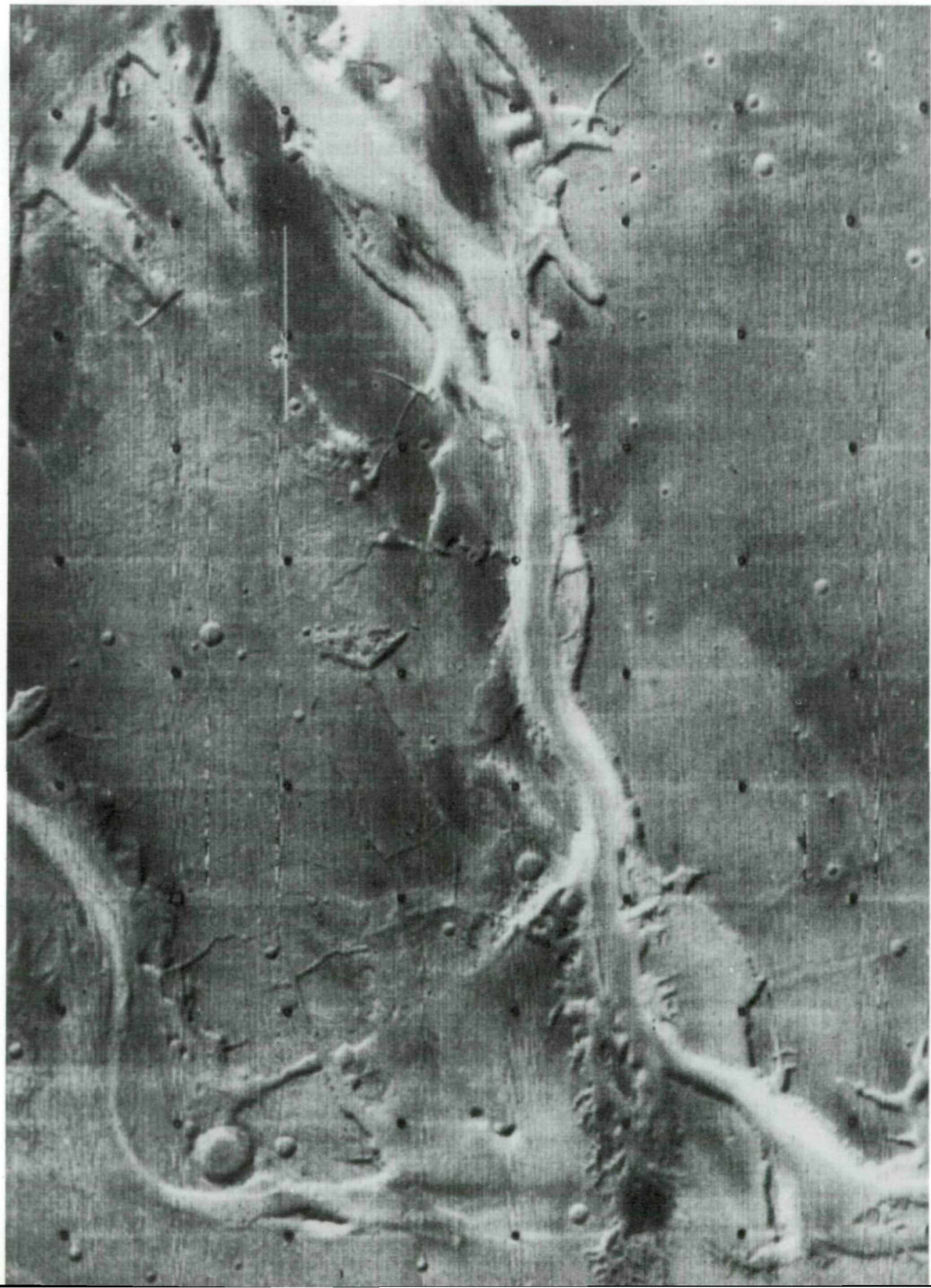
The photomosaic (above) of the lower part of the Amazonis channel in Mangala Vallis shows complex braiding such as streams produce in arid environments on Earth by depositing suspended sediment rapidly and intermittently. The streamlining of the "islands" very strongly implies formation by running water. Patterns like this have not been observed in lava channels on the Earth or Moon. The cuspness of the channel floor indicates that it was formed in geologically recent times; other martian channels are cratered and degraded as though much older. The crater seen along the right margin is about 20 km in diameter.—H. Masursky

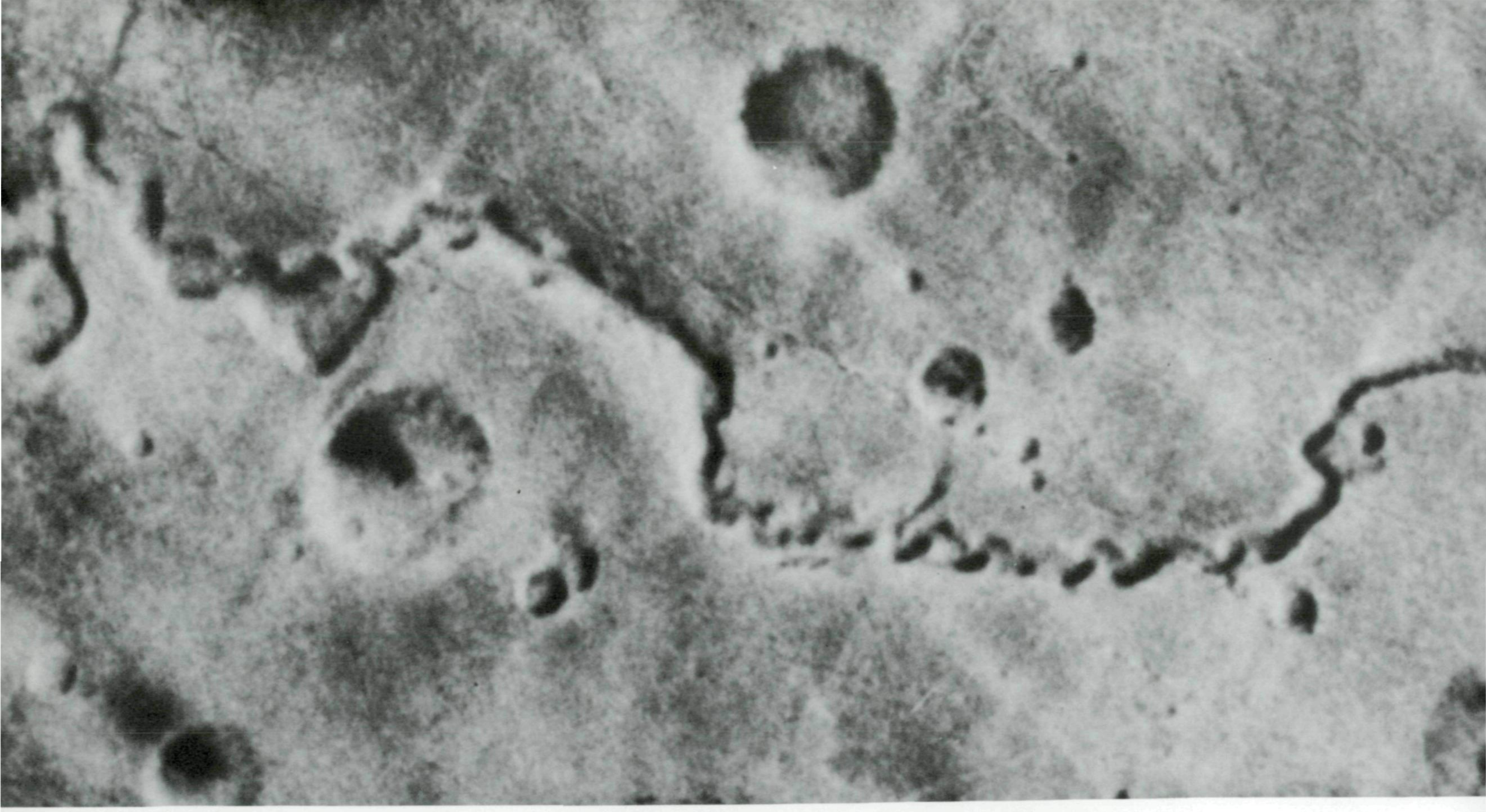
(31°N, 229°W; IPL 1441/152627)

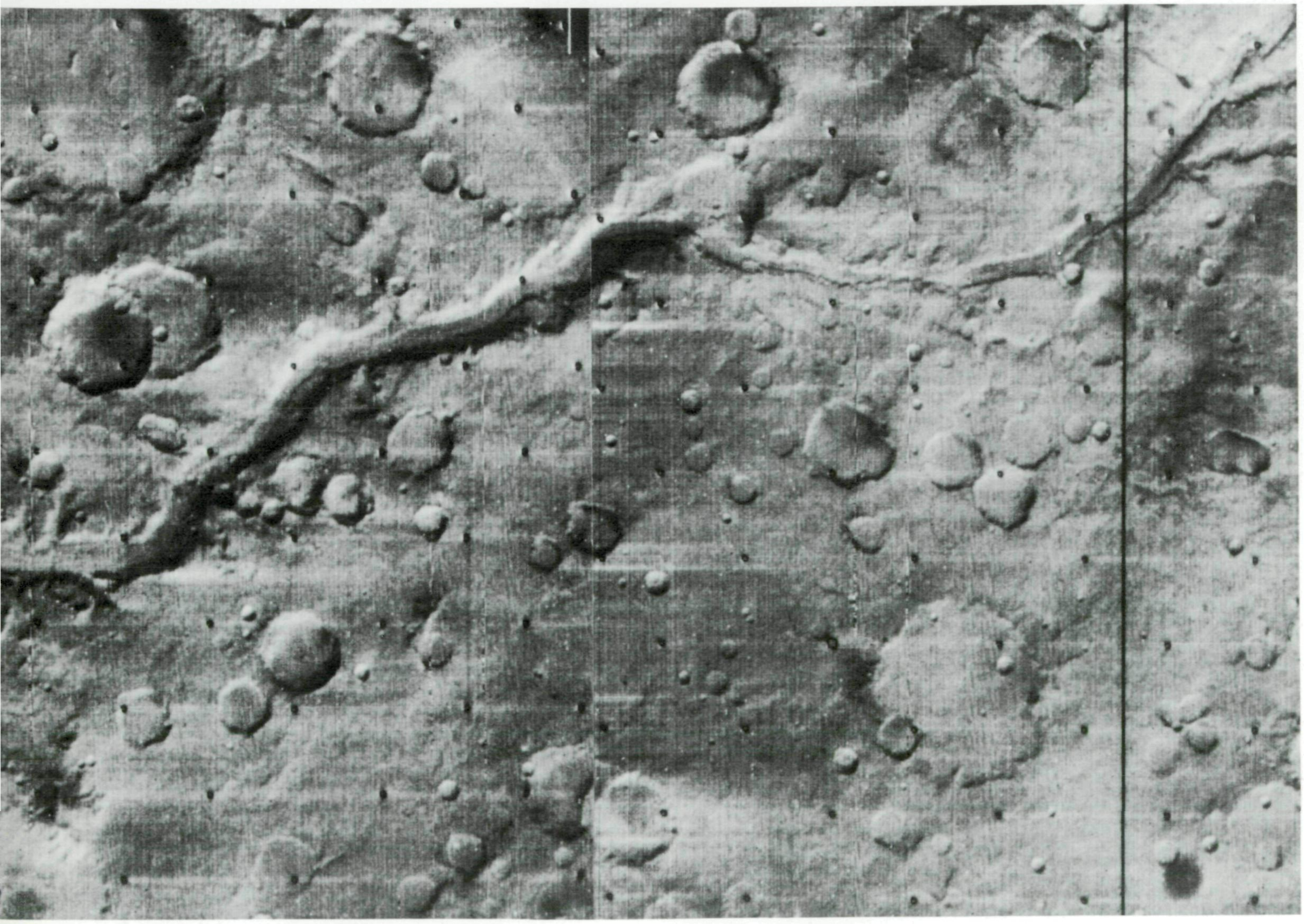
The channel at left (about 45 km wide) represents a sinuous multi-channel course containing discontinuous marginal terraces, teardrop-shaped islands (blunt ends face upstream) and macro braided channels. The character of this channel indicates that it might have been eroded by fluids. This channel arises in a hummocky area and perhaps the fluids resulted from melting of ground ice or permafrost. The only terrestrial examples of such large sinuous channels occur in the channeled scablands of the Columbia Plateau in the United States and the Sandier plains of Iceland, where release of great volumes of water resulted in catastrophic erosion.—H. E. Holt

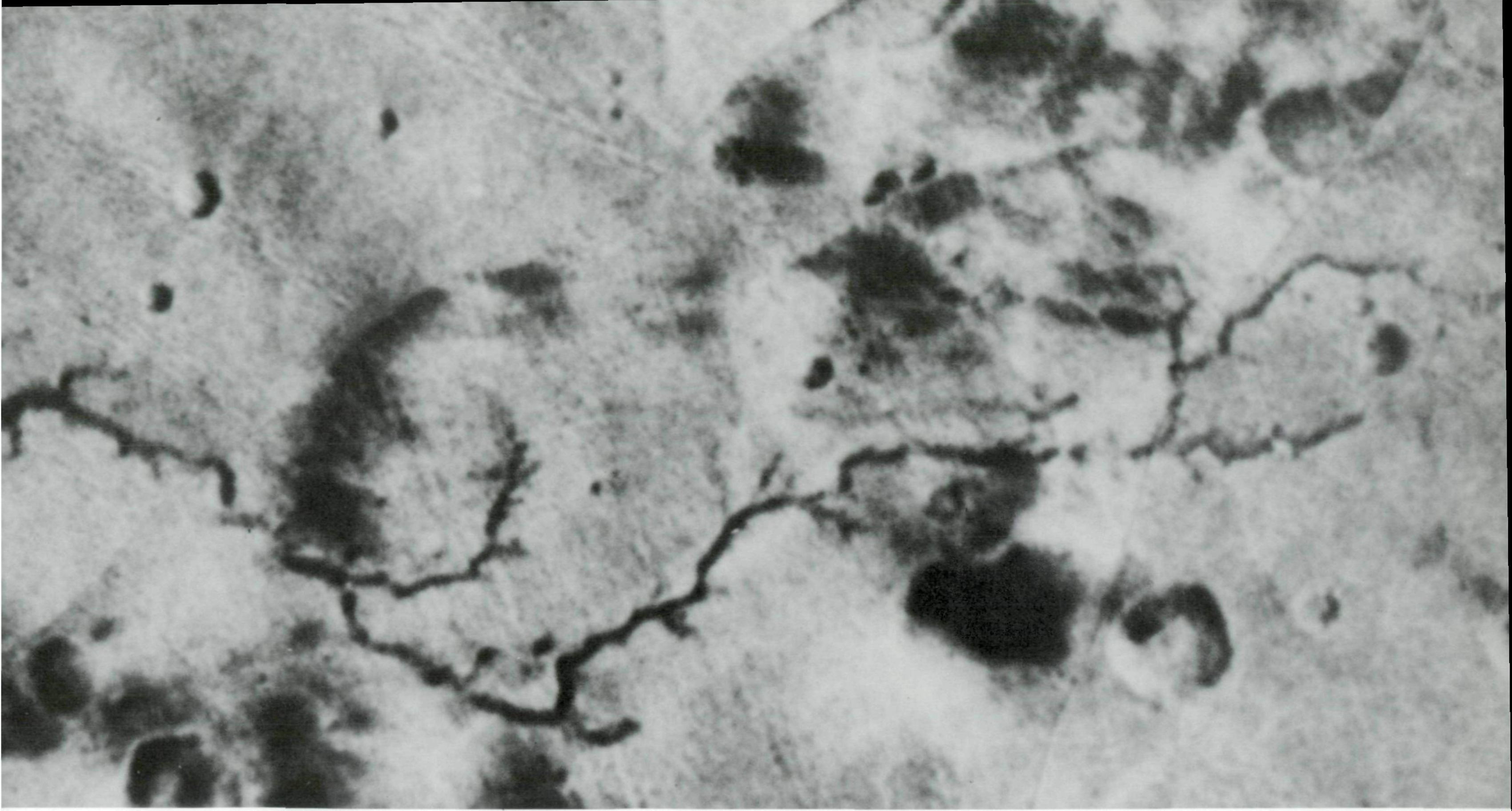
(23°N, 68°W; IPL 1628/143620)
(22°N, 73°W; MTVS 4297–7, 4297–15)

A 700 km length of a southern channel in the Kasei Vallis is seen below. The flow direction of this channel is eastward into the Chryse Planitia. An area in the lower part of the photo (partly concealed by a dark circle produced in the Mariner television system) is shown in the high resolution mosaic at right (approximately 75 km wide). A dendritic canyon system appears to have developed along an angular fracture set by headward growth. Note the smooth-floored channels. Wind scour has etched relief features across the upper plateau level. The ejecta from the large crater form a distinct bench and are believed to be accentuated by the greater resistance of the ejecta blanket to wind erosion.—H. E. Holt







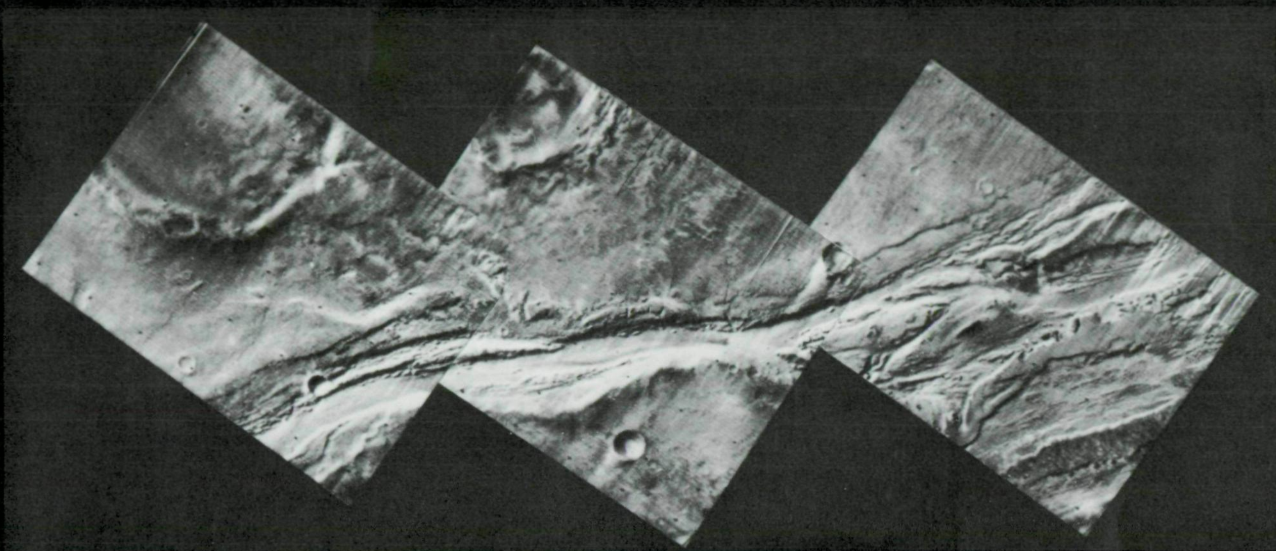


(29°S, 40°W; IPL 434/211030, 7462/40724, MTVS 4158–87)

The channel above is about 600 km long and 5 to 6 km wide. The lower reaches (top left) resemble the sinuous rilles of the Moon; the upper portion (top right) is more reminiscent of entrenched desert arroyos on Earth. The meandering and dendritic form of this channel is convincing evidence that a fluid once flowed on and eroded the planet's surface.—H. Masursky

(20°S, 184°W; IPL 454/200454, 454/203110)

This pair of low resolution photographs (left) shows a sinuous valley, Ma'adim Vallis, about 700 km long. The valley resembles shorter sinuous rilles on the Moon. The previous existence of fluids is strongly implied by the widening and deepening toward the mouth of the channel and the multiple branched tributaries toward its head. Water could not exist in the present climate of Mars, so a different climate in the past is suggested.—H. Masursky

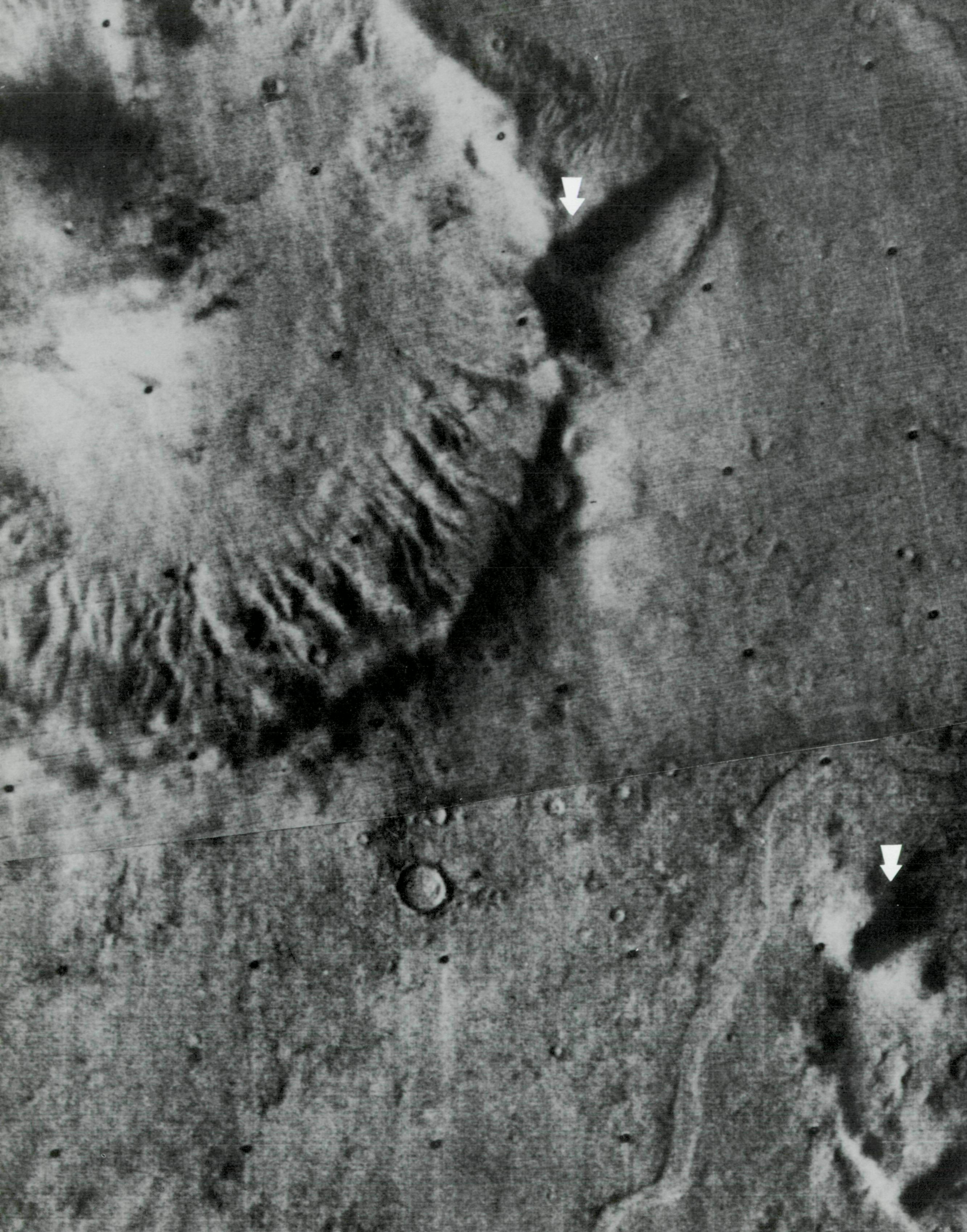


(7°S, 151°W; MTVS 4294–20, 4294–16, 4294–12)

Middle section of the Amazonis channel in Mangala Vallis where direction of flow is from right to left (south to north). The braided channel at right converges into a slightly sinuous main channel, 2 to 3 km wide, containing large bars and streamlined islands along the streambanks. Several levels of stream terraces occur along the east bank (top side of channel) which indicate several stages of stream erosion. The stream terraces, bars, and braided channels suggest that the streambed was eroded by running water where the quantity of stream flow fluctuated, perhaps becoming an intermittent stream. The individual frames cover an area about 30 by 40 km.—H. E. Holt

(45°N, 116°W; MTVS 4182–96)

The frame at right, about 60 km across, shows the eroded, undulating surface on a flank of Alba Patera. The fine textured dendritic pattern of deep gullies suggests erosion in unconsolidated material. An atmospheric source of water is suggested by the closeness of the channel heads to hill crests and by the presence of channels on both sides of elongated hills. Spotty distribution of such channels on the martian surface may have a climatic basis or merely be ascribable to obscuration of many gullies by wind erosion.—H. Masursky

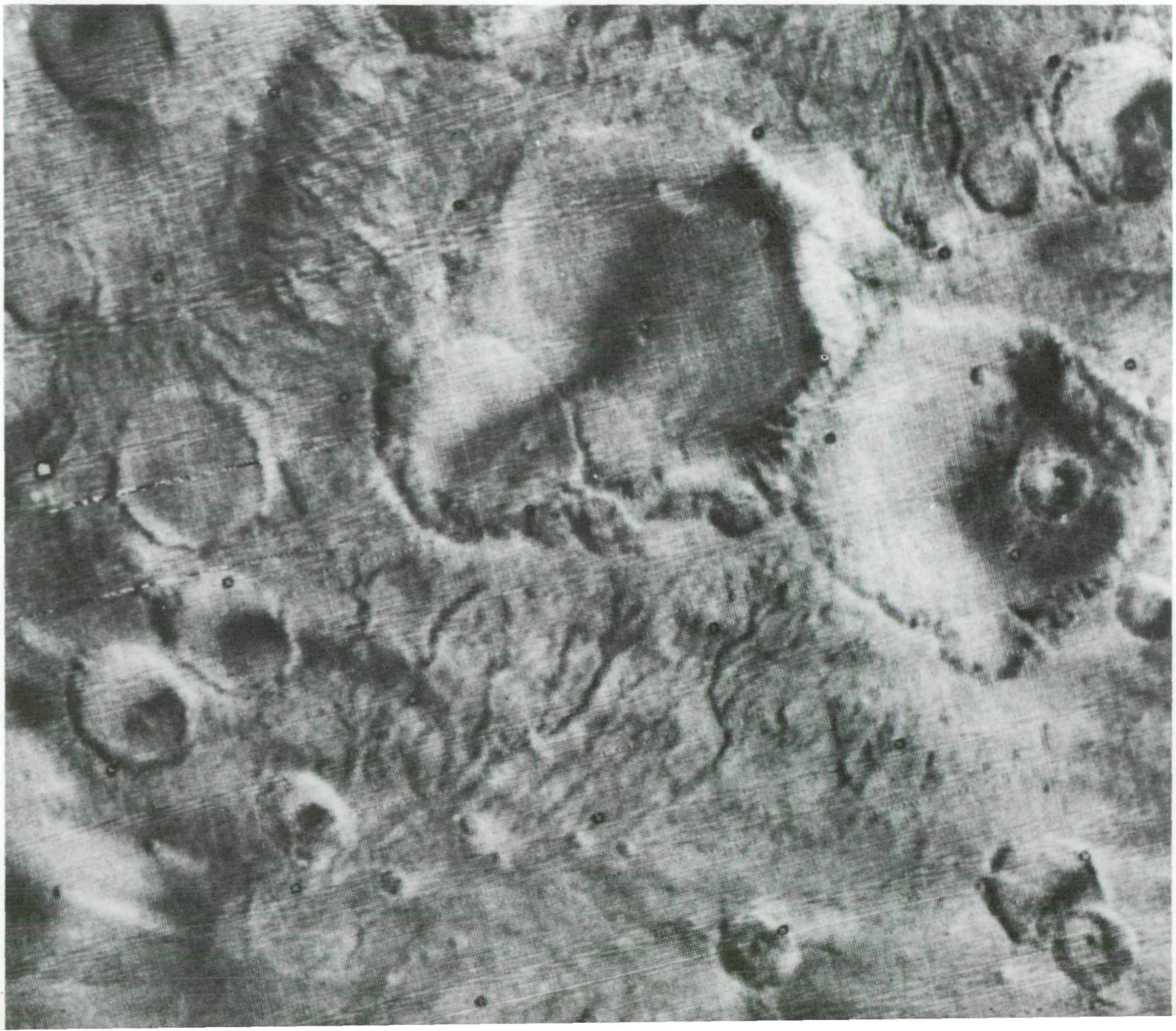


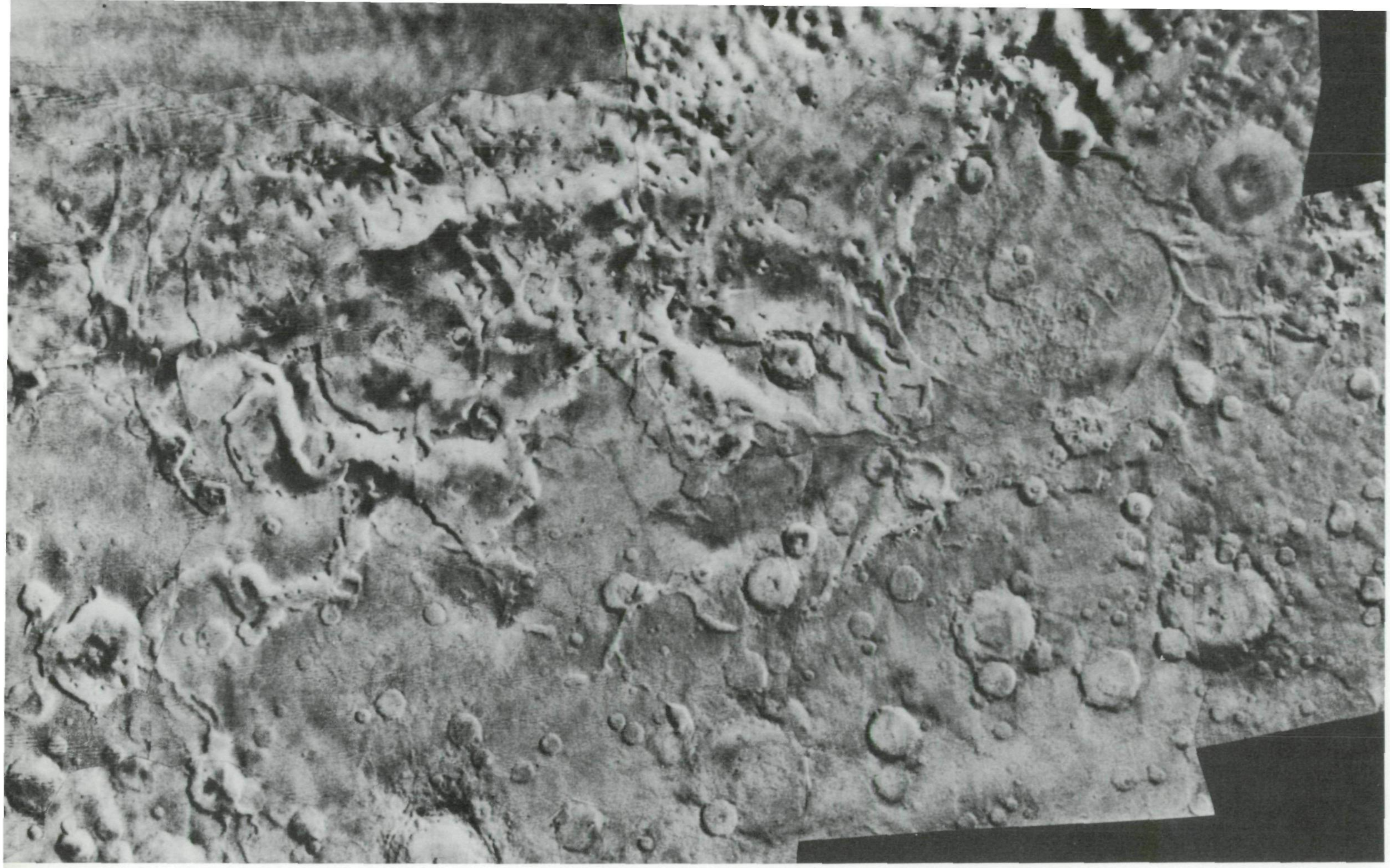
(36°S, 248°W; MTVS 4244–27, 4244–31)

The gullies on the inner wall of a 35 km wide impact crater, northeast of Hellas Planitia, suggest erosion by fluids. The origin of the gullies near the summit of the inner wall does not exclude melting ground ice as a source of fluid. The spur leading from the right rim may be of volcanic origin, as suggested by the multiple sinuous linear features and by the conical peak (arrow) at the junction of the rim and spur. In the bottom right of the picture, a small steep volcanic cone (arrow) having a barely discernible summit crater is visible. It is part of an east-west array of similar small conical hills, that is perhaps a volcanic chain. The channel nearby is a tributary to a major 1300 km long channel which drains southwestward into Hellas.—D. B. Potter

(9°S, 330°W; IPL 7243/111916)

Gullies have eroded into the rims of old impact craters (below). Picture width is about 330 km. The patterns resemble gully systems on moderate slopes in terrestrial deserts, and may have been formed by runoff of precipitation.—M. A. Sheldon



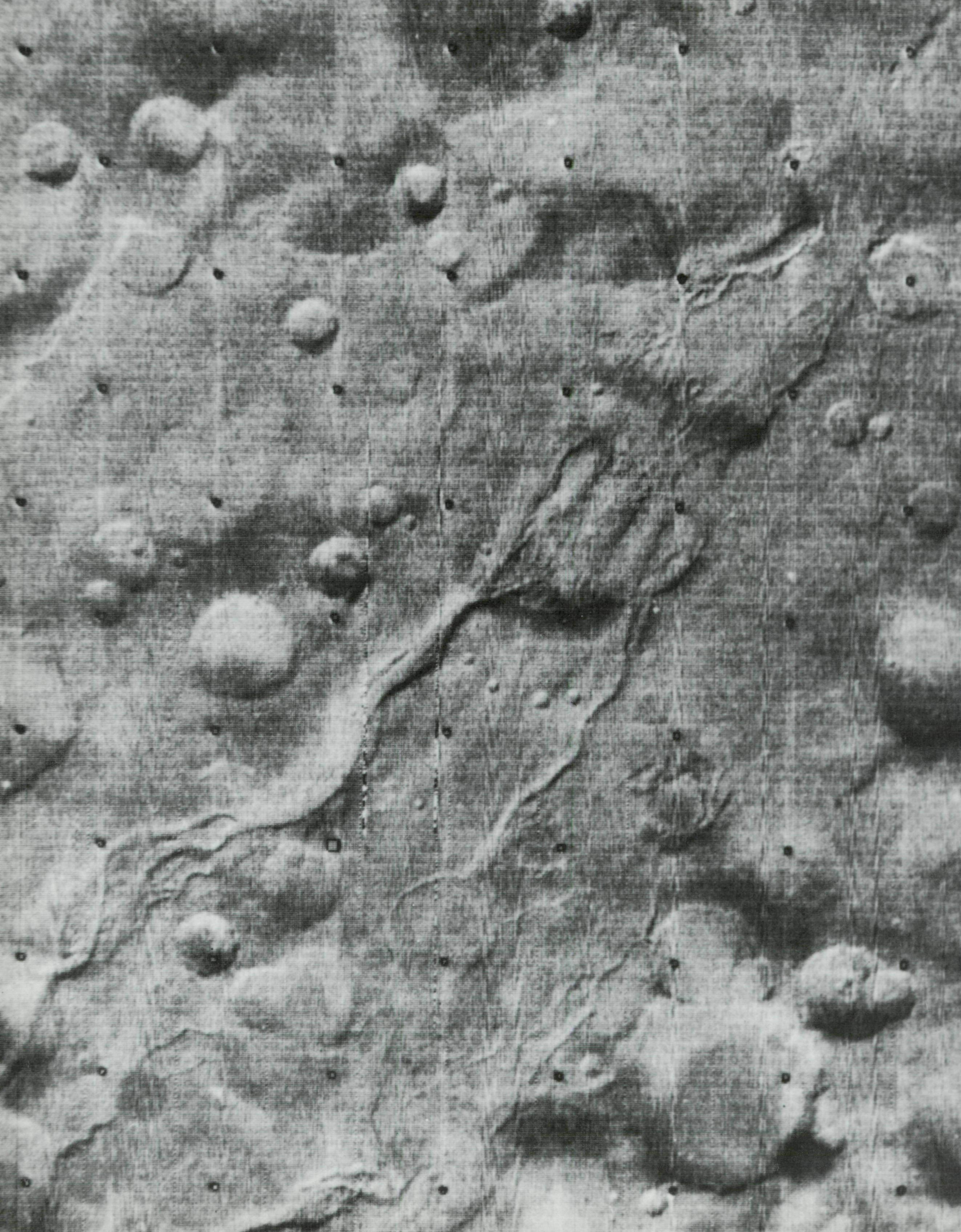


(38°N, 330°W)

This mosaic of low resolution photographs (above) shows the margin of a heavily cratered upland and the northern lowland that at the time was partially covered by clouds of the martian north polar hood. The edge of the highland is dissected by many sinuous and anastomosing channels that apparently are eroded into the highland. The channels shown here and those near Alba are at 45°N, the farthest north that channels have been perceived on the planet. The most abundant channels on Mars lie about 10° south of the equator.—H. Masursky

(6°N, 22°W)

The channel in this mosaic (right) of an area associated with collapsed terrain descends north into the Chryse Planitia. The Chryse lowland is a low part of the martian surface and a part of the lowland that girdles the planet. The channel slopes northward about 5 meters per kilometer for 1200 km and is about 30 km wide. It may have been produced by release of water from chaotic terrain near its head by melting of permafrost. The channel is degraded (that is, some braided forms are visible) and somewhat cratered, indicating an intermediate geologic age.—H. Masursky



(8°S, 151°W; IPL 1691/160649)

A complex of meandering valleys (left) cut through cratered terrain and debouch onto smooth plains in the upper part of the picture. As the valleys are traced downslope, irregular dendritic furrows coalesce to form a few major channels.—T. A. Mutch

(7°N, 45°W; IPL 1634–134231)

On the edge of the Chryse Planitia, canyoned terrain (below) shows prominent channels and rilles. The conspicuous light-dark boundary divides areas of unequal crater density. The lighter area has fewer craters; hence, it is probably a younger surface and it may be composed of a surface covering of fine particulate material that is being redeposited after erosion by the channels.—E. A. King, Jr.

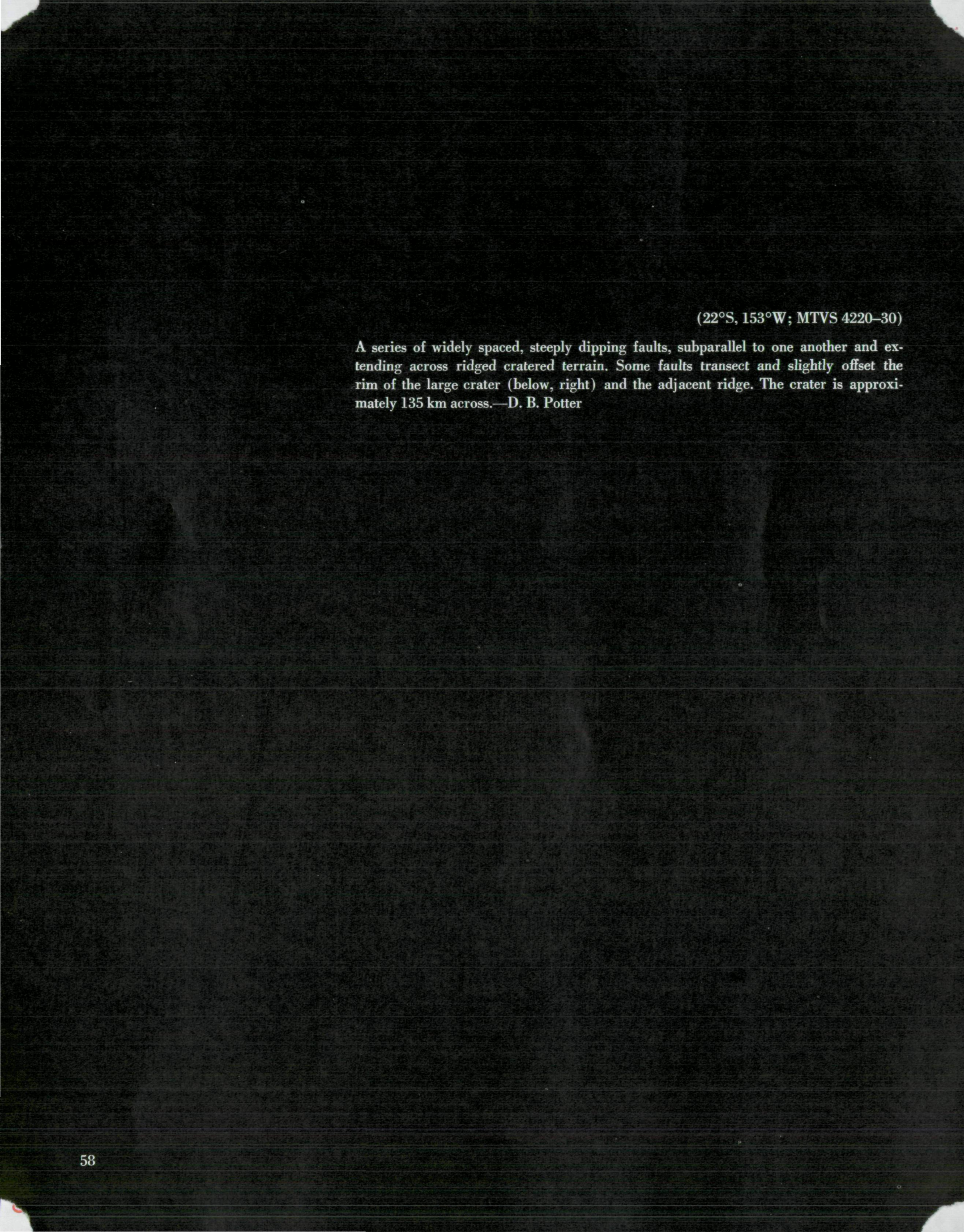
5 Fractures and Faults

Fractures and faults are abundant on the martian surface. Faults extending radially from craters and isolated fractures thousands of kilometers long indicate the response of the martian crust to changing stress conditions.

Surface fractures associated with large shield volcanoes and domes may result from the upwarping of the crust; possible later withdrawal of subsurface magma and concomitant collapse may produce faults. Radial and concentric fractures are also present in crater fields, and are due presumably to the tremendous shock of impact and subsequent readjustment of the crust.

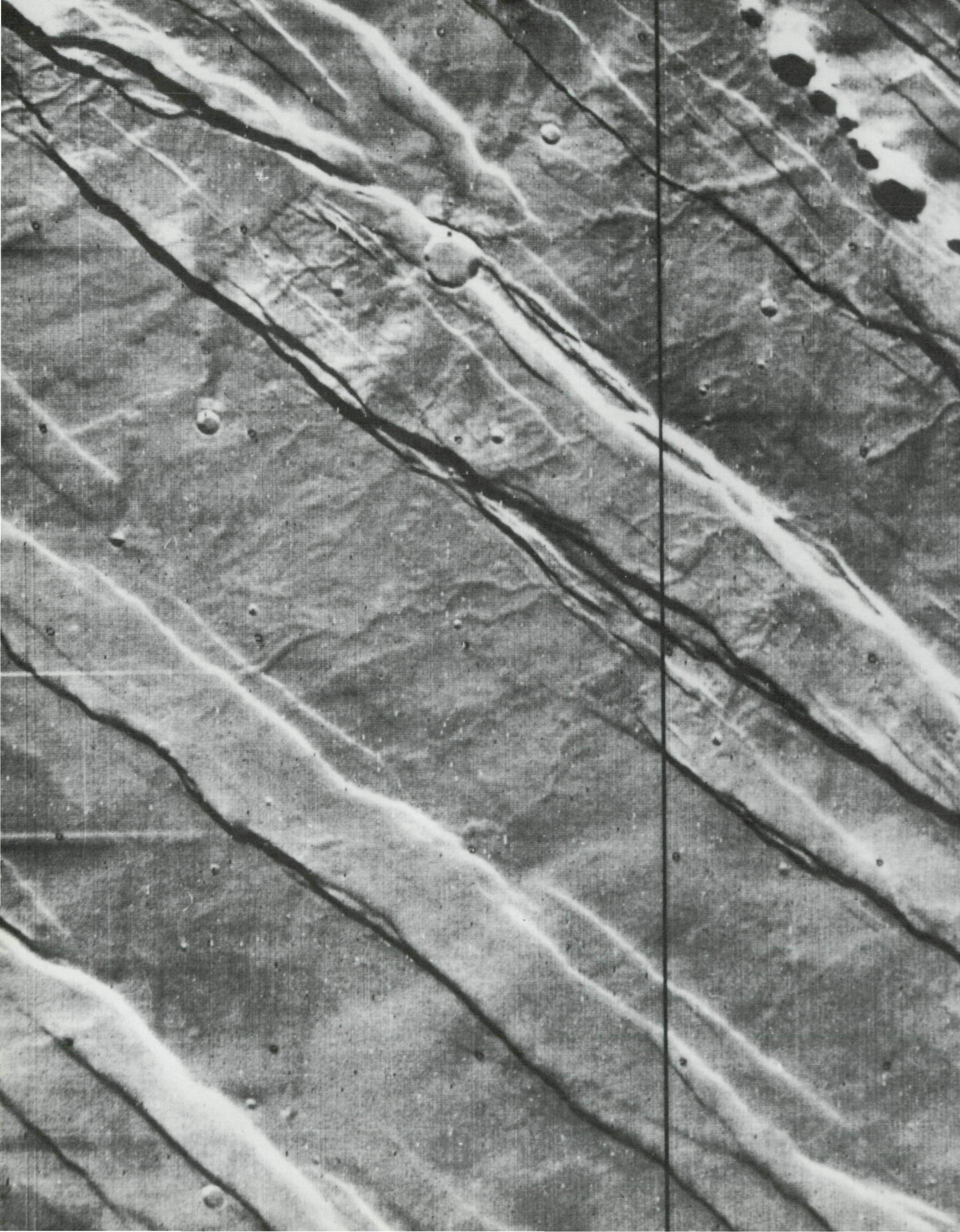
The most common fracture-related feature is the graben: a valley formed when the area between two approximately parallel faults drops down relative to the areas on each side. Many grabens are radial to the Tharsis volcanic field, suggesting that the broad uplift of the volcanic field and the attendant stretching produced many sets of faults and, subsequently, grabens.

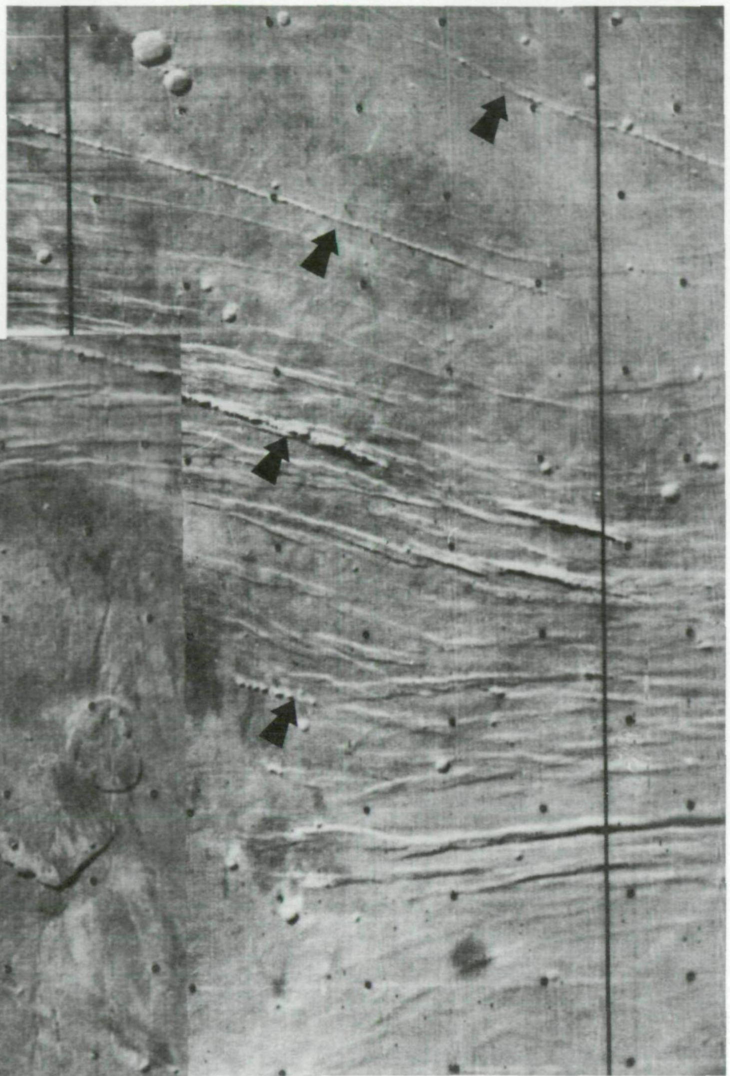
Fractures in volcanic regions commonly serve as weak or dilatant zones through which lava can escape to the surface, giving rise to an alignment of volcanoes or flow features. These alignments serve as an indication of now obscure fractures. Fracturing and faulting of the surface may also determine the trend of an escarpment of canyon. Such structural control is indicated by the occurrence of linear escarpments, which commonly form intersections with other escarpments. — J. W. Allingham and J. S. King

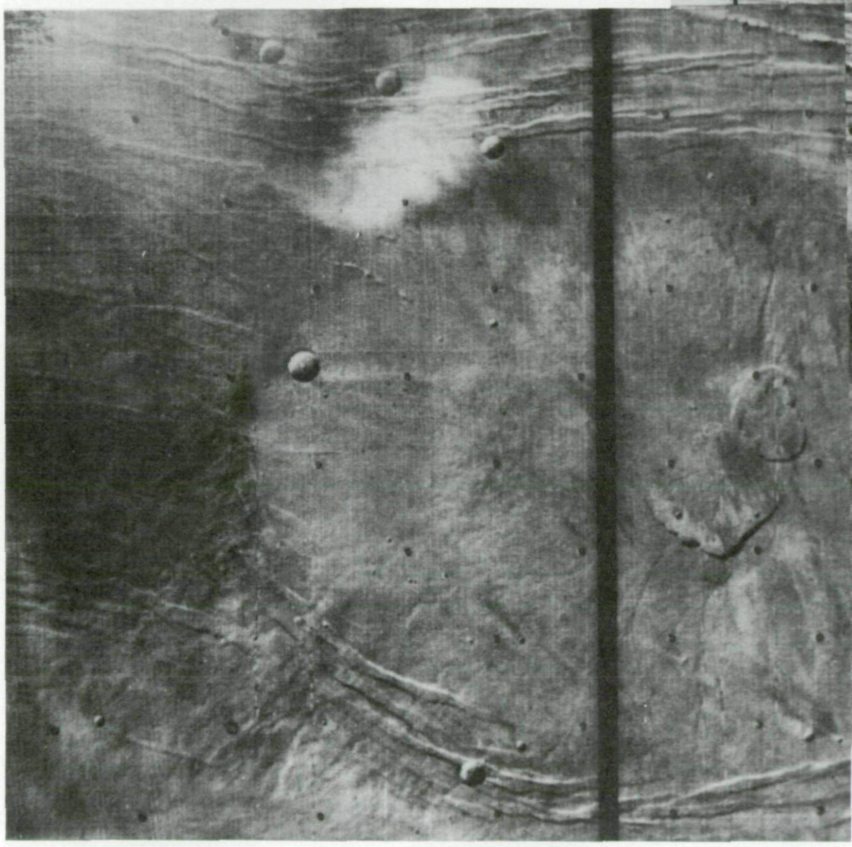


(22°S, 153°W; MTVS 4220–30)

A series of widely spaced, steeply dipping faults, subparallel to one another and extending across ridged cratered terrain. Some faults transect and slightly offset the rim of the large crater (below, right) and the adjacent ridge. The crater is approximately 135 km across.—D. B. Potter







(40°N, 108°W; IPL 1950/95214, 1950/130813)

A system of graben (above), partly deflected around a volcanic complex, form a ring about 650 km across. Part of the system is buried under volcanic material. At least four parallel, narrow rilles (arrows) cut across the graben system. These rilles, or crater chains, probably are linear arrays of volcanic vents. The longest rille shown is more than 400 km in length. Note that some graben are arranged en echelon.—J. E. Peterson

(38°N, 104°W; IPL 1428/223550)

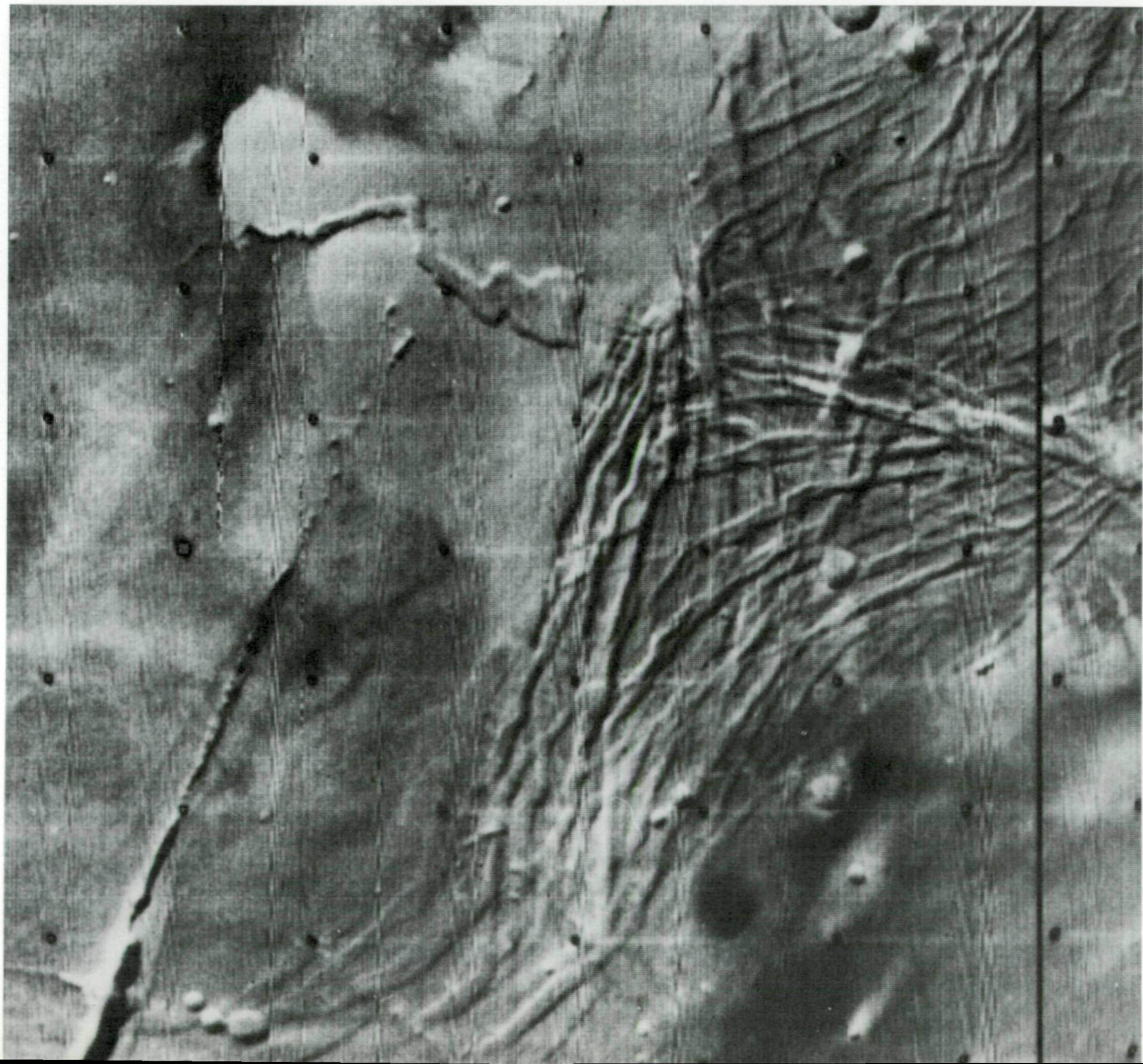
A detailed narrow angle view (left) of part of the graben system shown above (about 60 by 80 km). Multiple graben interrupt sinuous channels. Many fresh raised-rim craters are younger than the broken surface. A linear crater chain is present at upper right.—J. S. King

(17°S, 110°W; IPL 1563/130615)

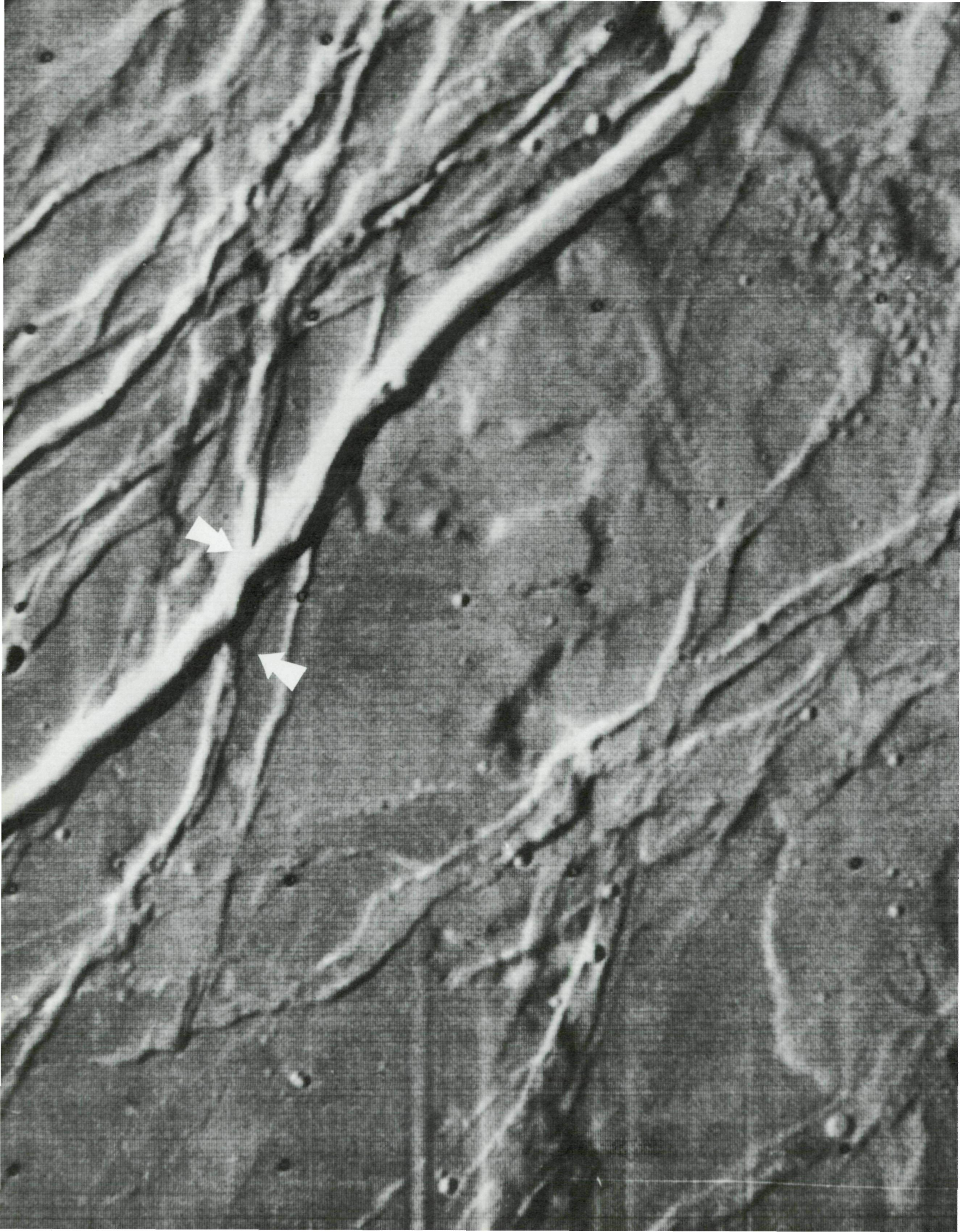
The intersecting and offsetting relationships between faults (right) in this high resolution view of part of the area shown below indicate the relative times and directions of movement of the faults. For example, graben A is offset by fault B, which is in turn cut by graben C. Thus A must be the oldest of the three, and C is the youngest. Fault B is a strike-slip fault (a fault which has lateral rather than vertical displacement). The crater is 7 km in diameter.—J. E. Peterson and H. Masursky

(15°S, 108°W; IPL 1108/144725)

A system of subparallel fault lineaments trending northeast to southwest clearly define a family of graben (regions which have been down-dropped relative to surrounding terrain). A second less obvious and older system intersects these. The faulted area is smooth plain material with only a few relatively young craters superimposed.—J. S. King




A
B
C

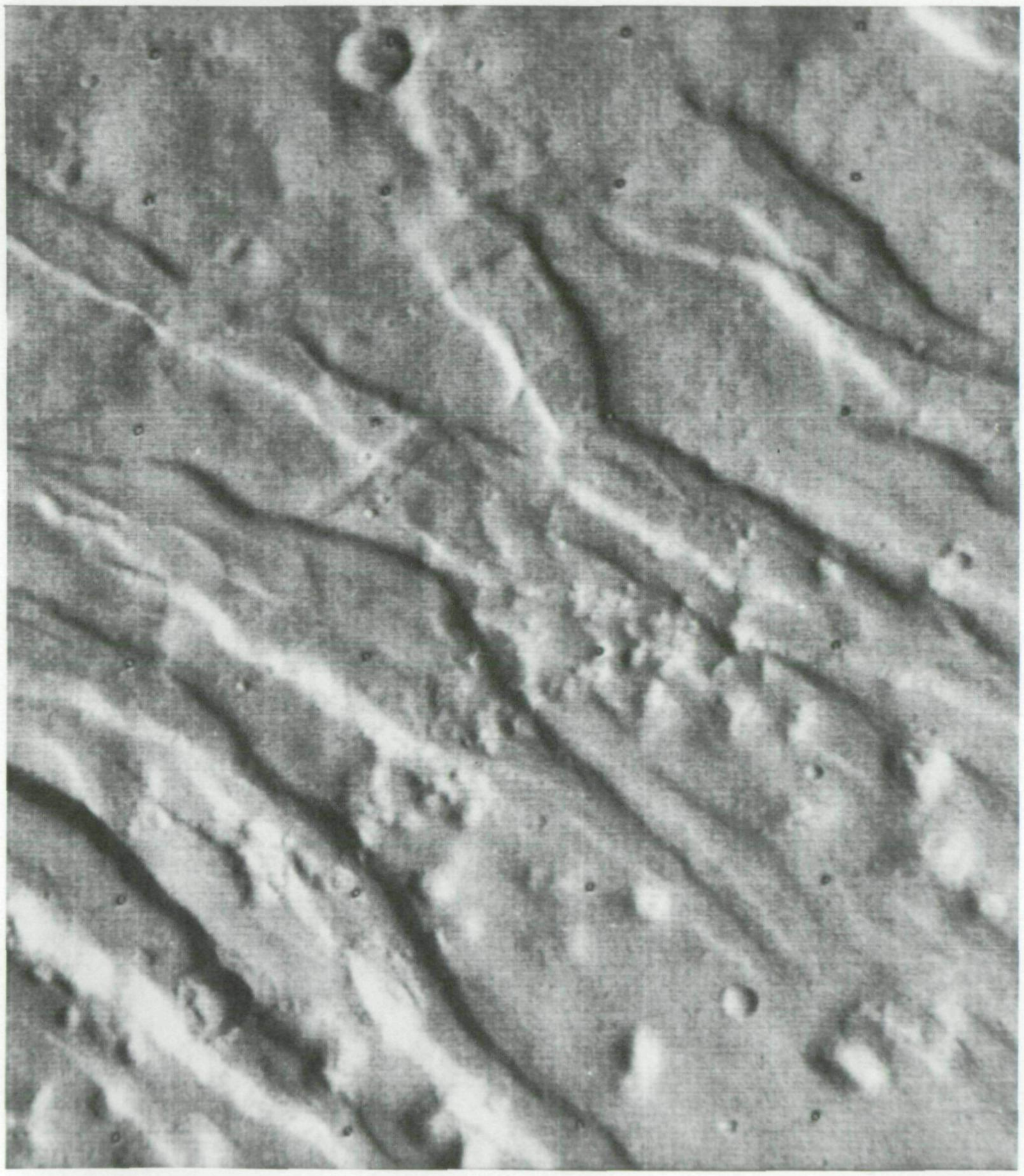


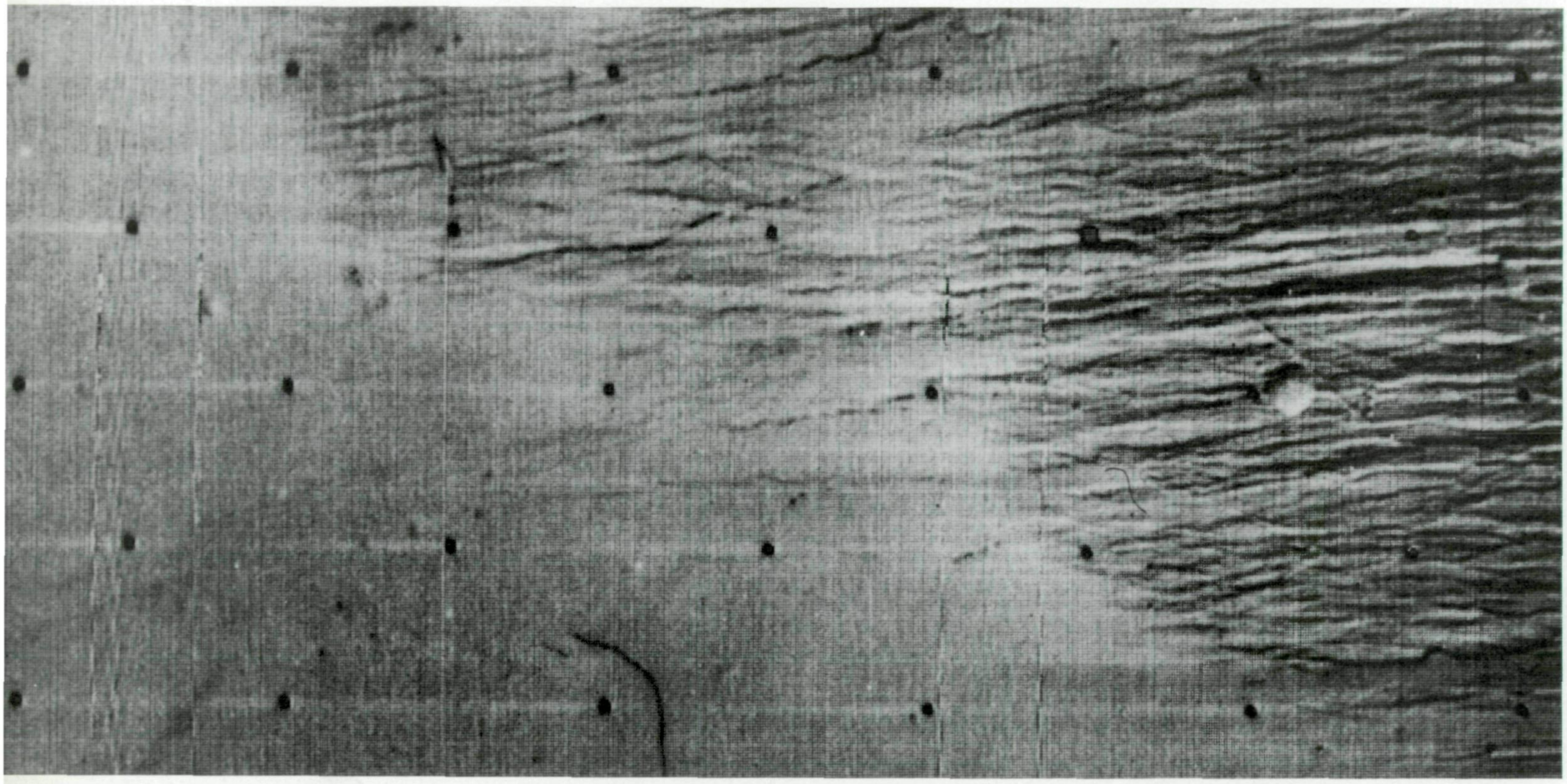
(31°N, 81°W; IPL 1434/180111)

Complex system of graben near the Tharsis Montes (left) showing some graben offsetting older graben. The ejecta blankets of large craters partially cover some graben in the lower right of this picture, indicating an early age for much of the fracturing. Fluid flow in larger flat-bottomed graben may have modified walls and deepened valleys. Note the hanging valleys (arrows) on the sides of the deepest graben, which is 2 km wide.—J. W. Allingham

(38°N, 140°W; MTVS 4256–60)

A high resolution view (below) shows the gradual fading of the graben into the plain and possible evidence of fluvial modification of the graben. A second set of faint graben crosses the more prominent set. Note the tiny conical volcanoes (center) adjacent to the faults bounding the grabens. The area is about 45 km wide.—J. W. Allingham



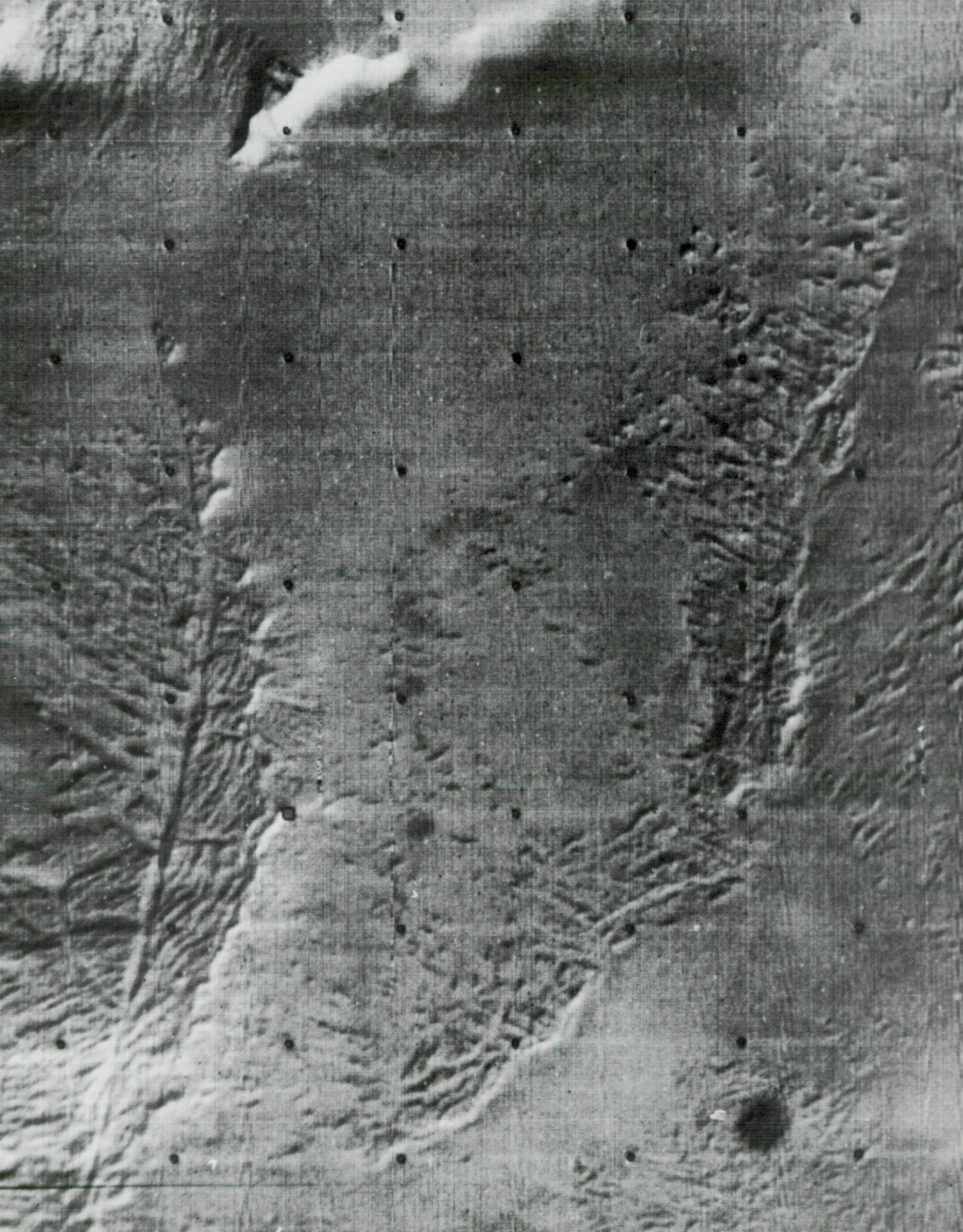


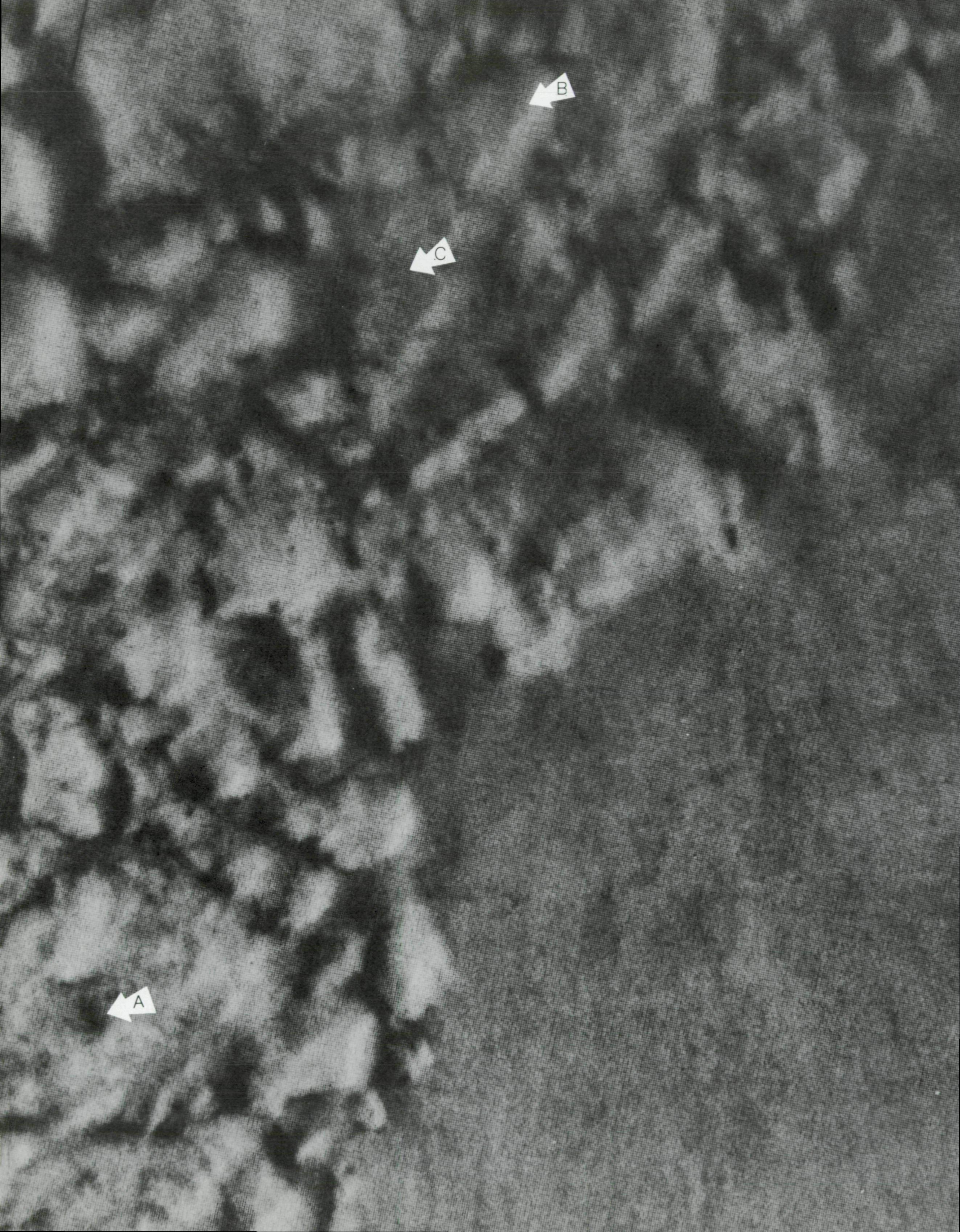
(21°S, 106°W; MTVS 4184–90)

This fractured plain is located east of Olympus Mons and north of Ascraeus Mons. The pattern is almost certainly controlled by a major set of north-south trending fractures, Claritas Fossae. The impact crater in the fractured plain is about 20 km in diameter.—J. E. Peterson

(16°N, 142°W; IPL 497/191619)

Grooved terrain forms a discontinuous aureole around Olympus Mons (right). It consists largely of closely spaced low ridges and intervening linear troughs that in high resolution pictures appear to have been wind scoured. The troughs almost surely represent a complex array of fracture zones that are less resistant than the surrounding materials to wind erosion. The origin of this terrain and its relation to Olympus Mons remains a puzzle. Some investigators have suggested that it represents an early outpouring of lava or ash from Olympus Mons that have since eroded back to the pronounced scarp that now surrounds this enormous volcanic edifice. The picture is about 365 km wide. —J. F. McCauley




B
C
A

(34°S, 177°W; IPL 1422/174345)

Rugged hills, 0.5 to 8 km across, rise abruptly from a smooth, lightly cratered plain. A small cone (A) may be a volcano, and other hills may be volcanic domes. The straight valleys which separate some hills, escarpments (B), and flat hilltops (C) indicate formation of this hilly terrain by crustal fracturing and subsequent erosion.—J. H. Howard III and J. F. Woodruff

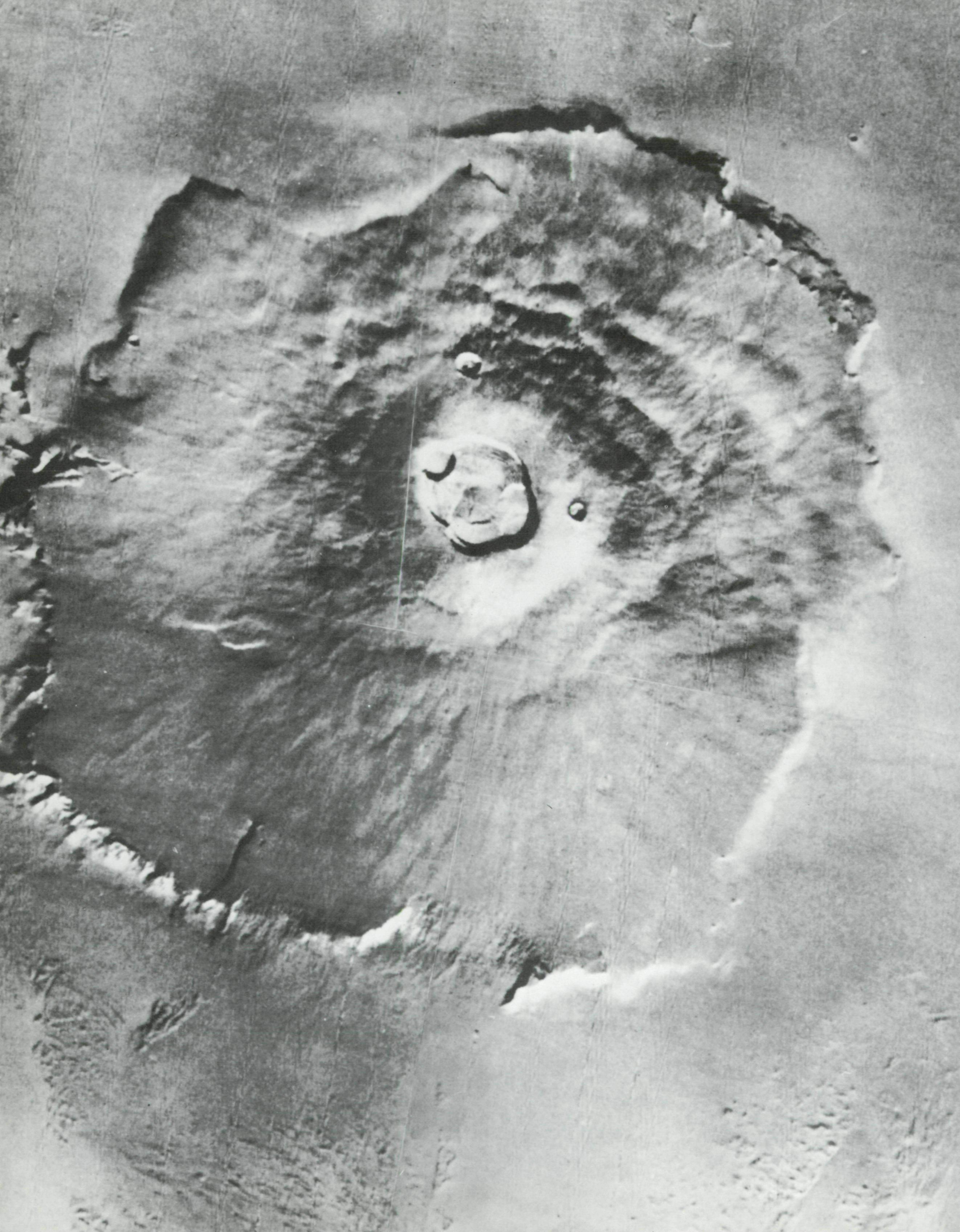
6
Escarpments

Long, steep cliffs occur on the surface of Mars. They are from 1 to 4 km high, and range up to several hundred kilometers in length.

Many escarpments have complex configurations and scars that suggest that some form of erosion has caused the scarp face to recede at the expense of the uplands. Numerous U-shaped chutes in the upper reaches of escarpments are similar to the scars left by debris avalanches on steep terrestrial slopes. Lumpy mounds of material below alcoves or gullies are indicative of debris slides or slow downhill movement. In regions bounding chaotic terrain, huge blocks that often retain their original flat tops have slumped downward and outward from the edges of escarpments.

In contrast to the deeply embayed and scarred cliffs, there are also long escarpments with straight, sharp brinks and few scars. Because of this configuration, this form of structure is thought to follow faults or fractures, and to have undergone little recession of the face.

In the polar and near-polar regions some scarps seem to be a product of erosion of layered material that mantle older, cratered terrain beneath. This observation suggests that Mars may have undergone alternating cycles of deposition and erosion, the latter attended by the developing of retreating scarps. — R. P. Sharp



(15°N, 130°W; MTVS 4265–48)

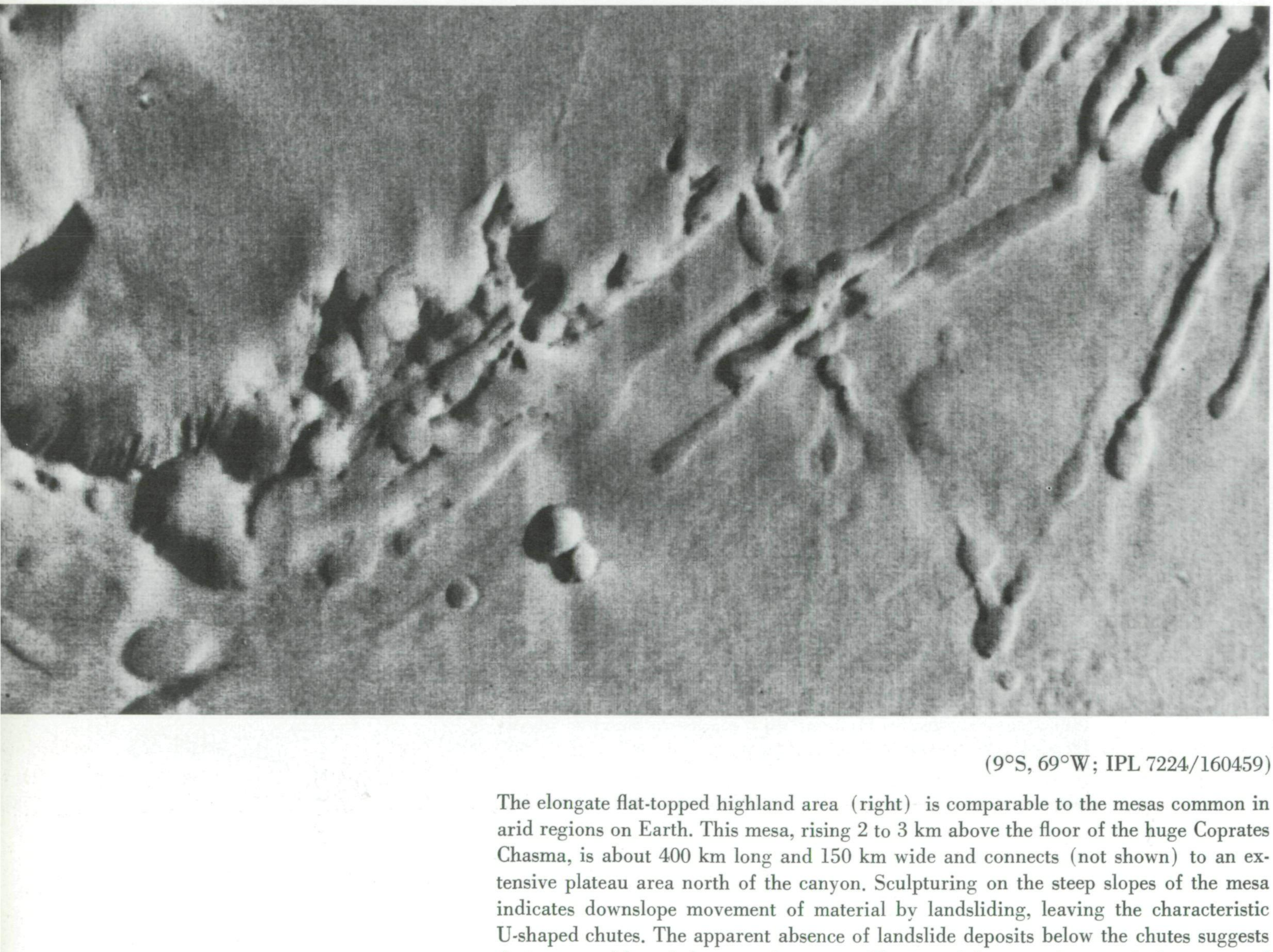
The southeastern portion of the Olympus Mons escarpment (above) shows a well defined base and generally a sharp rim with apparent slump scarps and terraces. The fluted, steep, upper part is partially covered by huge landslides or lava flows. The escarpment varies from 1 to 3 km in height. Residual block-like mesas indicate the remnants of a higher terraced surface on the flank of the volcano.—D. B. Potter

(18°N, 134°W)

The great escarpment (left) around the base of Olympus Mons, approximately 1500 km long, resembles a wave-eroded seacliff on a terrestrial volcanic island, but is not so easily explained as there are no martian seas. The escarpment appears sharp over more than half of its length; the remainder appears subdued. In a few places the scarp is absent, probably covered by lava flows or huge landslides. The origin of the escarpment is uncertain, but probably involves a combination of such processes as mass wasting and eolian erosion.—J. E. Peterson

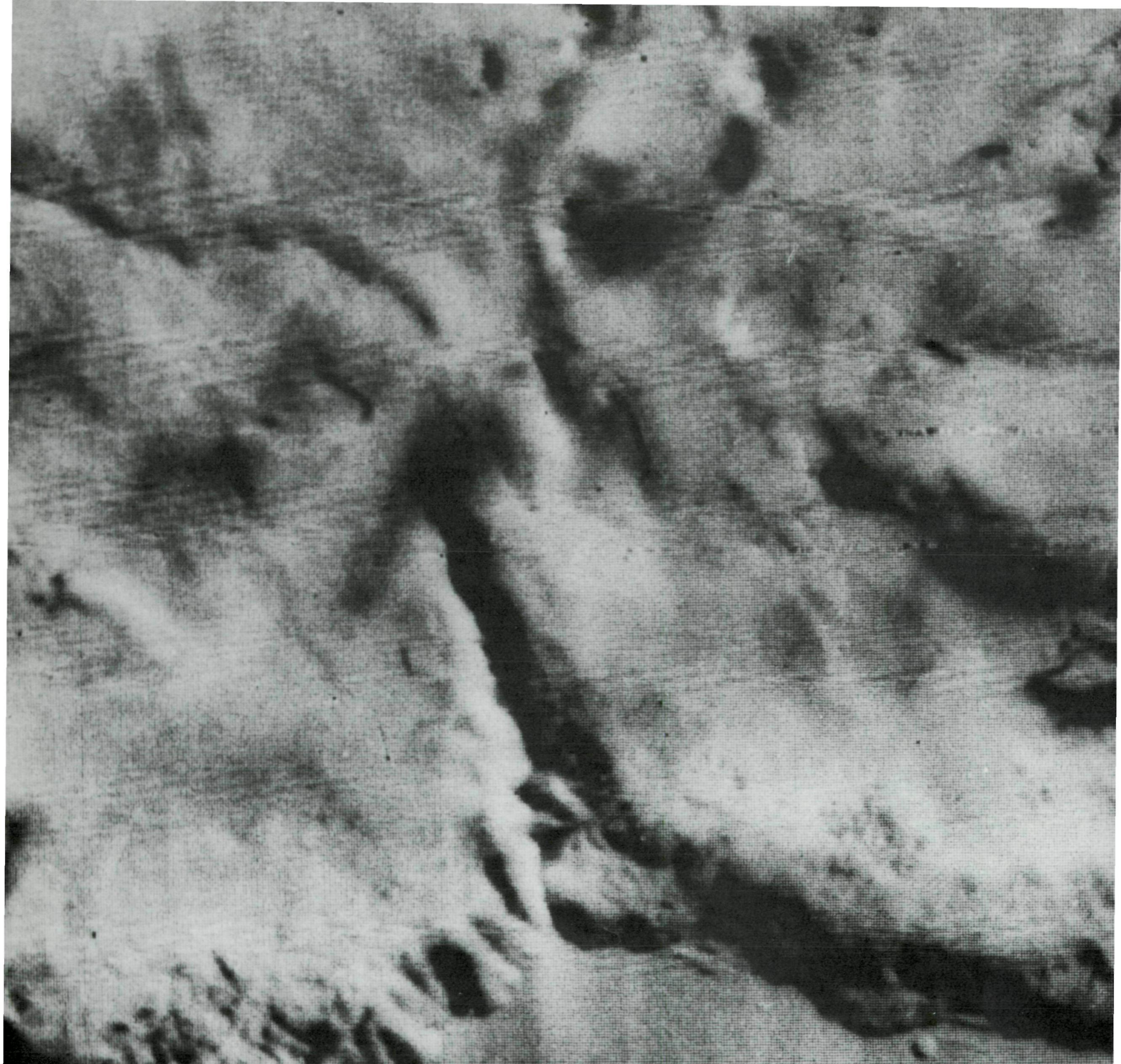
(2°N, 111°W; MTVS 4229–51)

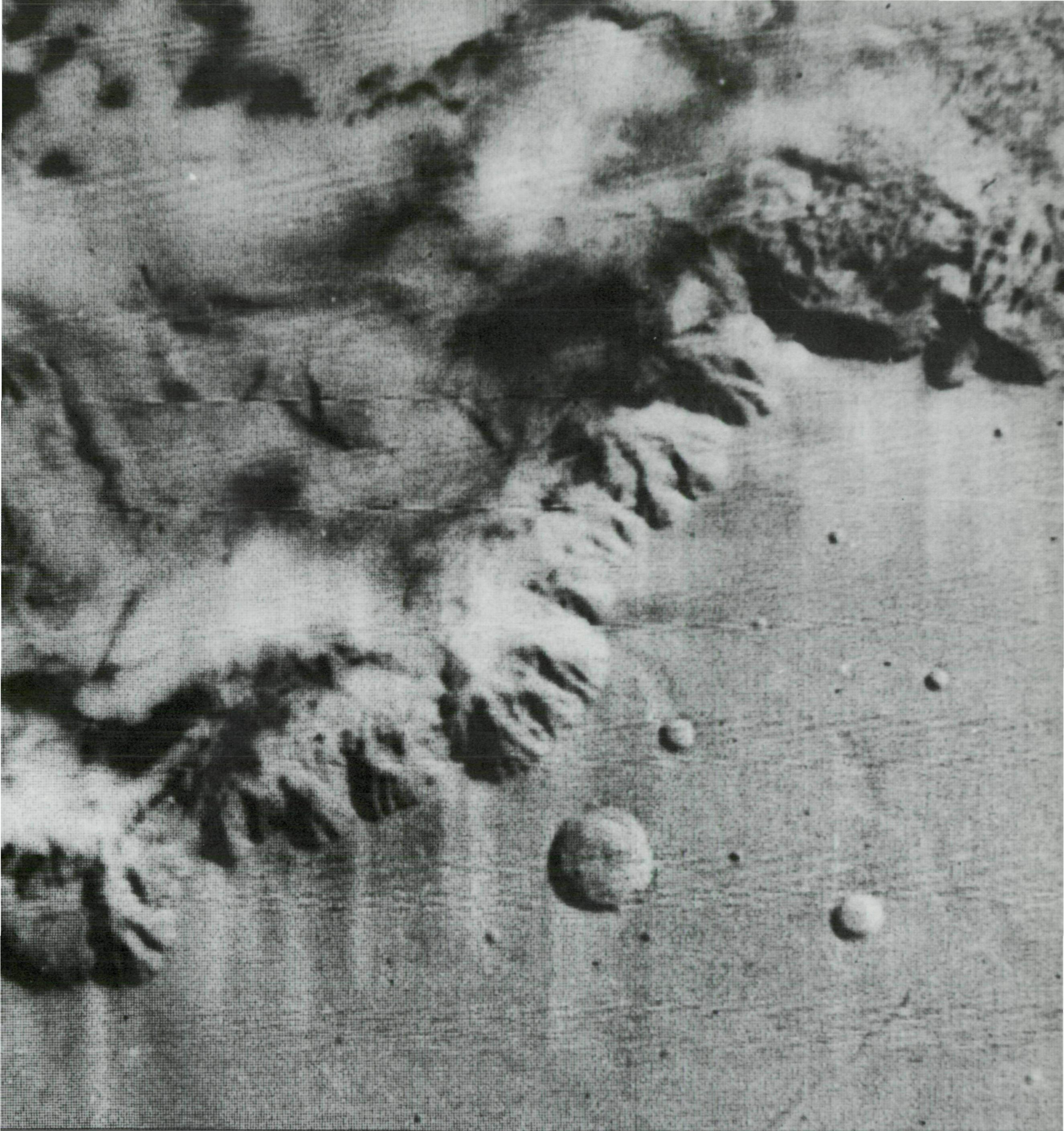
A detailed view of the northeast flank of Pavonis Mons (below) shows many features characteristic of collapse between fractures which are called graben. The graben trend northeastward, parallel to the Tharsis Montes. Rock chutes and ridges have been modified by wind action.—J. W. Allingham



(9°S, 69°W; IPL 7224/160459)

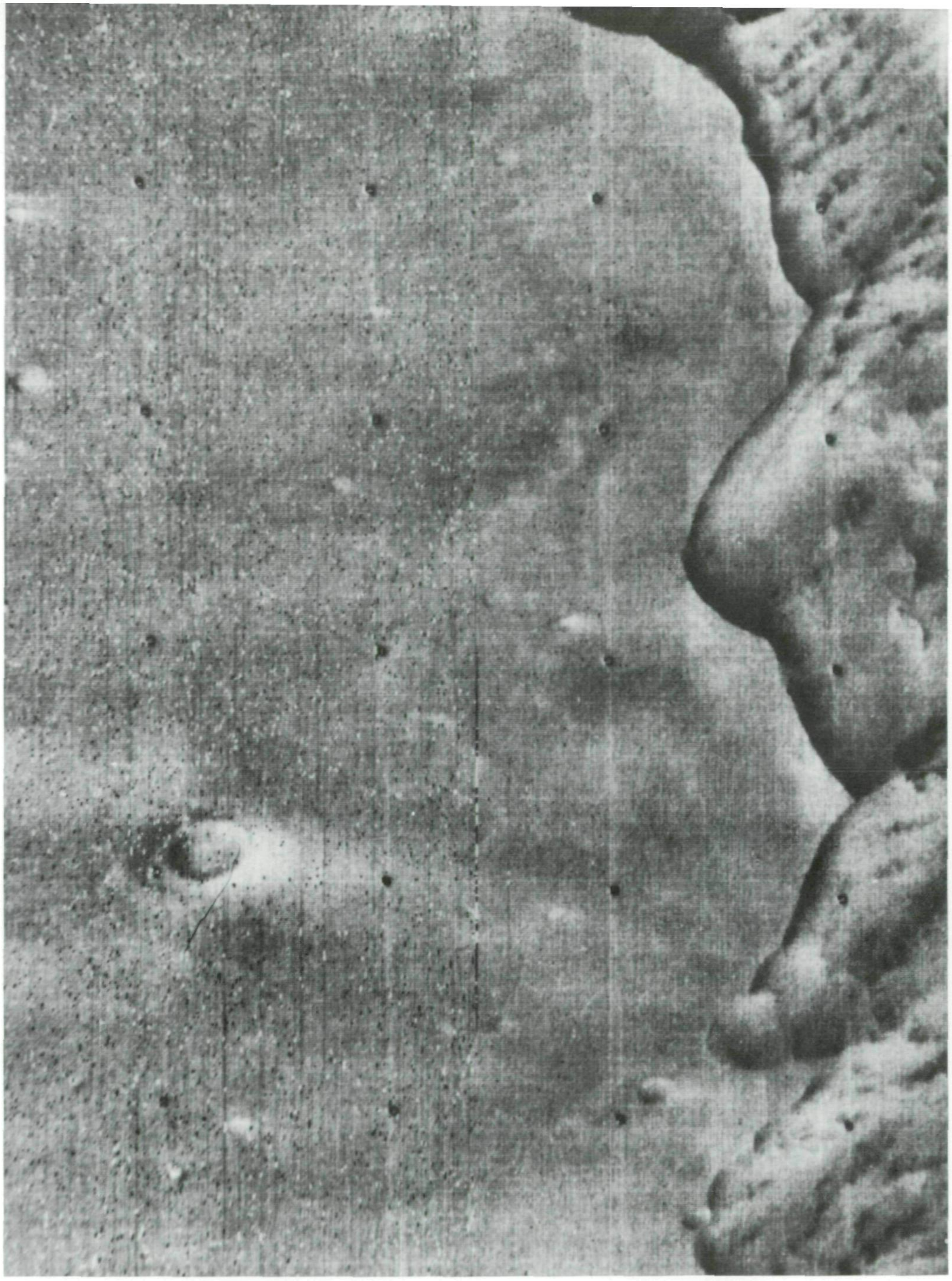
The elongate flat-topped highland area (right) is comparable to the mesas common in arid regions on Earth. This mesa, rising 2 to 3 km above the floor of the huge Coprates Chasma, is about 400 km long and 150 km wide and connects (not shown) to an extensive plateau area north of the canyon. Sculpturing on the steep slopes of the mesa indicates downslope movement of material by landsliding, leaving the characteristic U-shaped chutes. The apparent absence of landslide deposits below the chutes suggests their removal by wind or running water. The top of the mesa is extensively transected by faults, some of which occur in facing pairs so as to produce long, narrow troughs or graben.—G. E. McGill





(13°S, 71°W; MTVS 4195–33)

This arcuate escarpment, several kilometers high, is a portion of the south wall of Valles Marineris at one of its widest points, Melas Chasma. Erosion by mass wasting appears to be the dominant process involved in the escarpment retreat. Debris avalanche chutes are abundant along most of the scarp. Note the long ridge extending about 80 km into the canyon.—J. E. Peterson

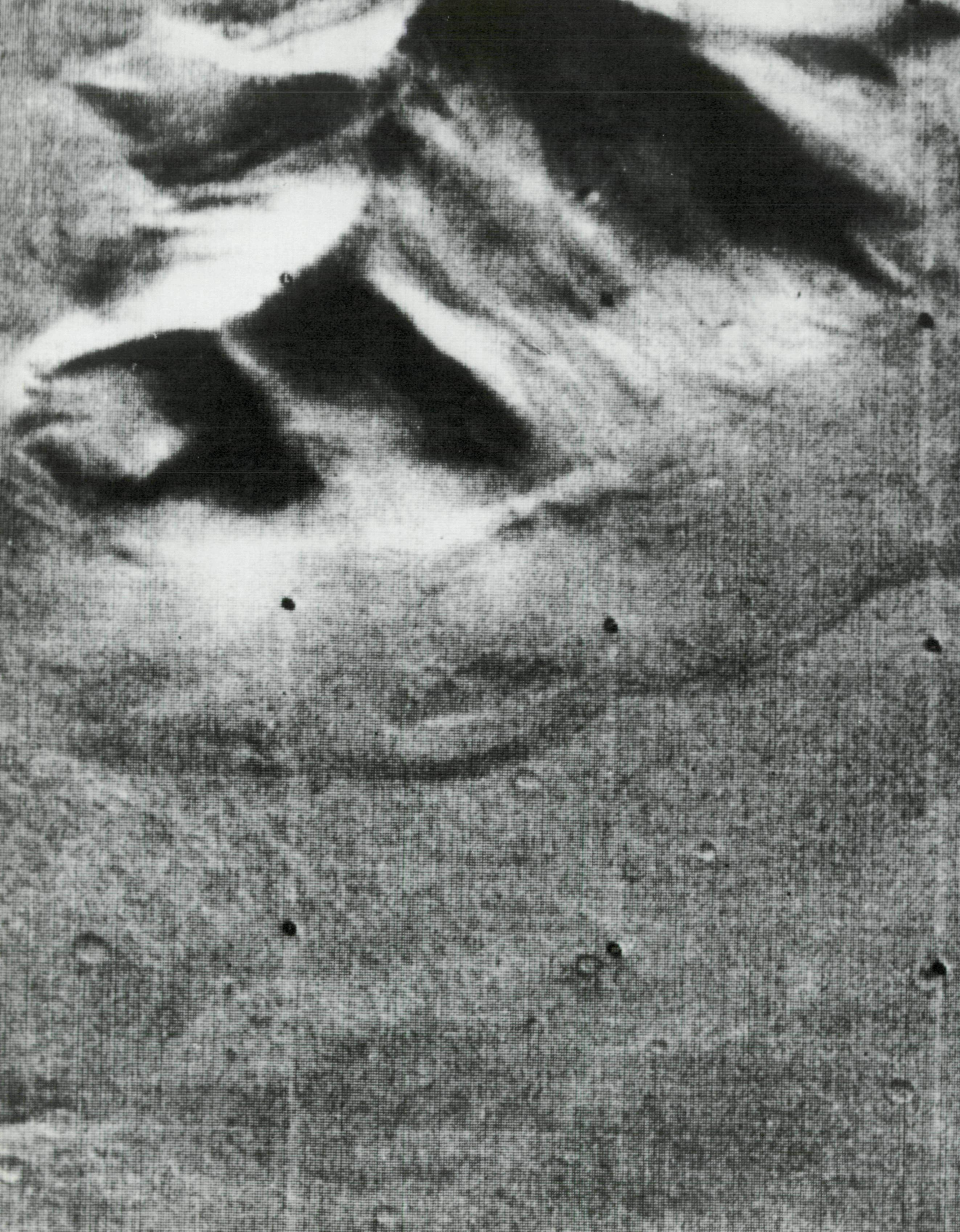


(12°S, 50°W; IPL 7464/235907)

The sharp rim edge along the northern edge of the equatorial plateau (above) indicates that resistant rocks underlie the plateau. The escarpment is 1 to 2 km high and alternating resistant and nonresistant rock layers are exposed on the cliff faces. These may be alternating lava flows and pyroclastic rocks as these exposures are not too far from the great volcanoes that may have acted as the source for the rocks. The rock layers may be from 100 to 200 m thick. The few impact craters on the surface of the plateau imply that it is geologically a young surface.—H. Masursky

(5°S, 85°W; MTVS 4275–36)

Detail of Valles Marineris wall and edges of the plateau. Note the apparent raised rim of the plateau and occurrence of bedded outcrops just below the rim. The picture is about 63 km wide and the escarpment is several kilometers high.—D. B. Potter



(41°S, 258°W; IPL 1445/105008)

This isolated bold mountain remnant on the plains at the east edge of Hellas Planitia is approximately 35 km wide. Its sharp ridges and spurs have a branching pattern indicating equal erosive attack from all sides. The steep upper slopes show mass wasting chutes and narrow tongues of material suggest some form of mass movement. Broader tongues of material occur along the western base. Around the base of the mountain is a wide apron sloping gently away from the mountain. This suggests slow mass movement of granular material over a long period of time.—D. B. Potter

7
Fretted and Chaotic Terrains

Fretted and chaotic terrains are lowland topographic forms on the martian surface which may be in part the product of related genetic agents. Fretted terrain is characterized by smooth, flat lowland areas with many flat-topped buttes and mesas resembling those in the western United States. Chaotic terrain exhibits rough floor topography of jumbled large, angular blocks. Both terrains are separated from cratered upland areas by escarpments having complex configurations.

A striking characteristic of fretted terrain is its irregular border pattern. The steep escarpment is smoothly sloping and free of slump blocks and typically traces a ragged course with deep embayments, projecting headlands, and numerous shallow scallops. The lowland floor of the fretted terrain is generally smooth, showing only a few scattered craters and low swells and swales.

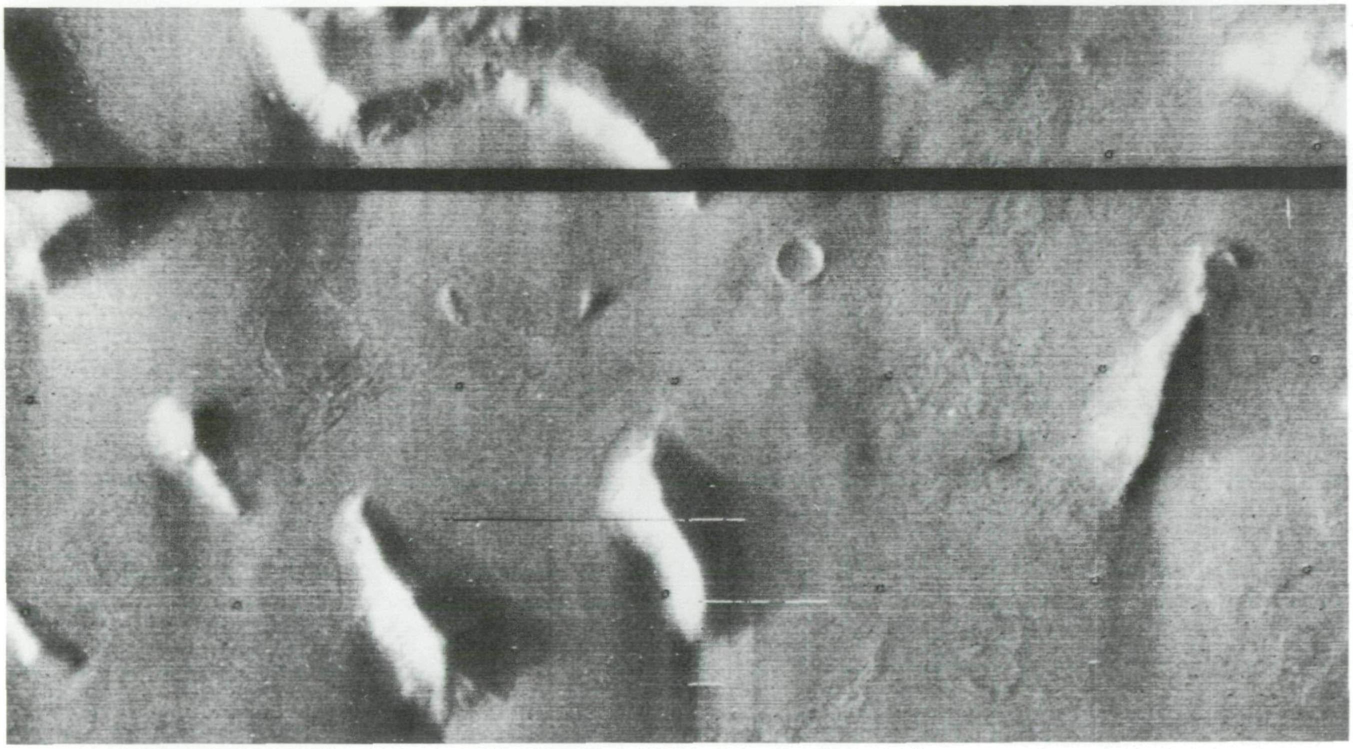
Some areas of chaotic terrain are sharply bounded by an abrupt escarpment of irregular configuration, while other boundaries exhibit a transition from slightly fractured upland through a highly fractured zone to a jumble of irregular blocks. The vertical relief of escarpments seems to range between 1 km and 3 km. They are higher than most escarpments bounding areas of fretted terrain.

The most distinctive feature of chaotic terrain is the rough-floor topography consisting of an irregular jumble of angular blocks up to several kilometers wide and tens of kilometers long, many bearing remnants of the relatively smooth upland surface on their tops. At some sites, the shape of the blocks appears to be controlled by intersecting sets of fractures resulting in blocks of almost equal dimensions. After formation, the blocks appear to undergo continuing breakdown and reduction in size, eventually being completely destroyed and leaving a flat, smooth floor similar to that of fretted terrain.

Fretted terrain, clearly developed at the expense of older cratered uplands, appears to be among the youngest of the martian landforms. The smooth floors of most areas of fretted terrain are only sparsely cratered, mostly by small, new craters. Chaotic terrain is judged to be equally youthful on essentially the same basis. Closely adjacent areas of fretted and chaotic terrain cannot be too different in age. However, the seeming paucity of craters within areas of chaotic terrain may be a result of difficulty in recognizing small craters within the chaos of jumbled blocks.

Subsidence and slumping having played a part in the development of chaotic terrain. Since these are usually initiated by the removal of subsurface material, the problem of the origin of chaotic terrain becomes one of identifying the material removed and the process, or processes, which accomplished the removal.

The development of fretted terrain is thought to be initiated by some structural break in the old cratered uplands. Once an escarpment is formed, it recedes by some type of undermining or sapping mechanism. The erosional removal of debris, perhaps by the wind, leaves a smooth, flat floor and isolates island-like buttes and mesas. The bounding slopes of these outliers also recede, reducing them in size until they disappear entirely. — R. P. Sharp



(44°N, 330°W; IPL 1417/224259)

A close-up view of erosional outliers in an area of fretted terrain. The height of the prominent features is at least 1 to 1.5 km. The undulating plain shows numerous swells and swales. The young, raised rim crater is about 3 km across.—R. P. Sharp

(43°N, 313°W; IPL 1651/154245)

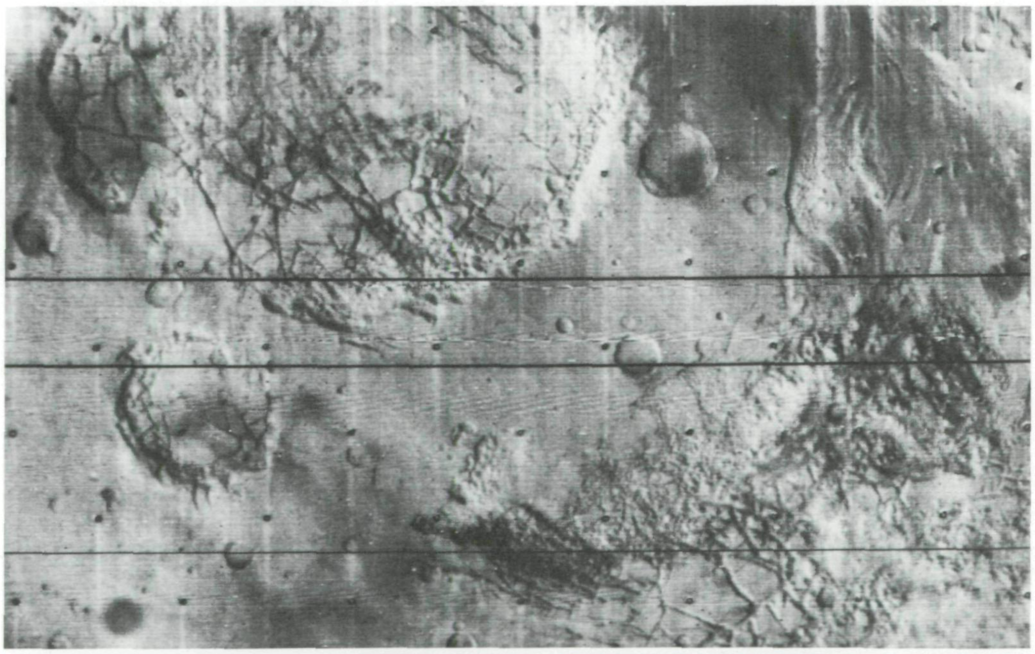
In this fretted terrain (left) at mid-latitude in the northern hemisphere, a relatively smooth lowland is separated from the old cratered upland by abrupt cliffs at least 1 to 2 km high. Mesa-like remnants and flat-floored chasms penetrating far into the upland are characteristic. This terrain is regarded to be a product of cliff recession caused by an undermining process operating at the cliff base. Material shed by the cliffs has been removed, probably either by fluvial transport, under different climatic conditions, or by eolian deflation.—R. P. Sharp

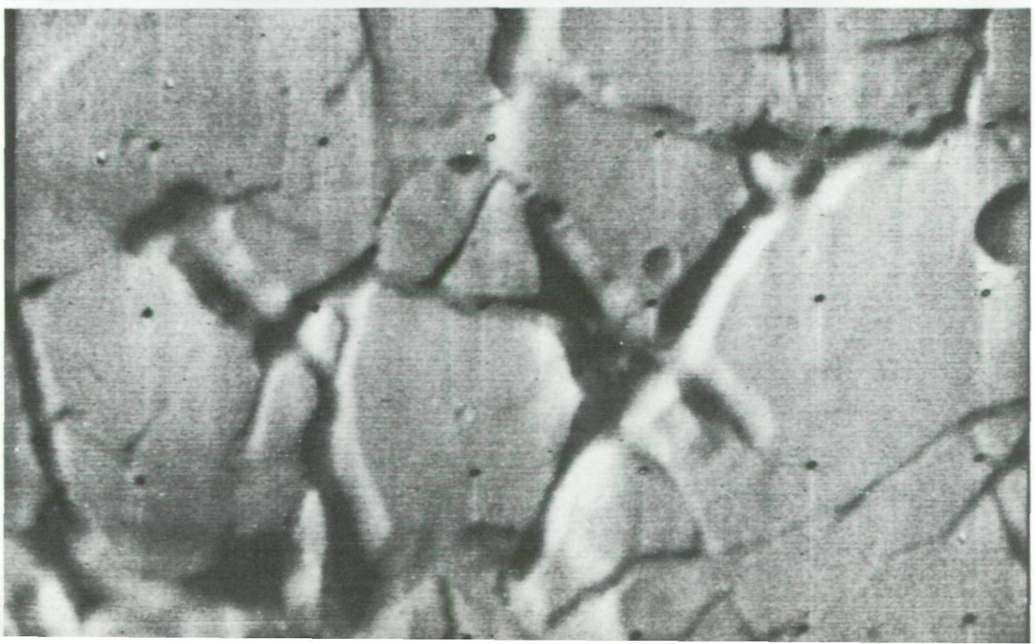
(3°N, 37°W; IPL 7350/165312)

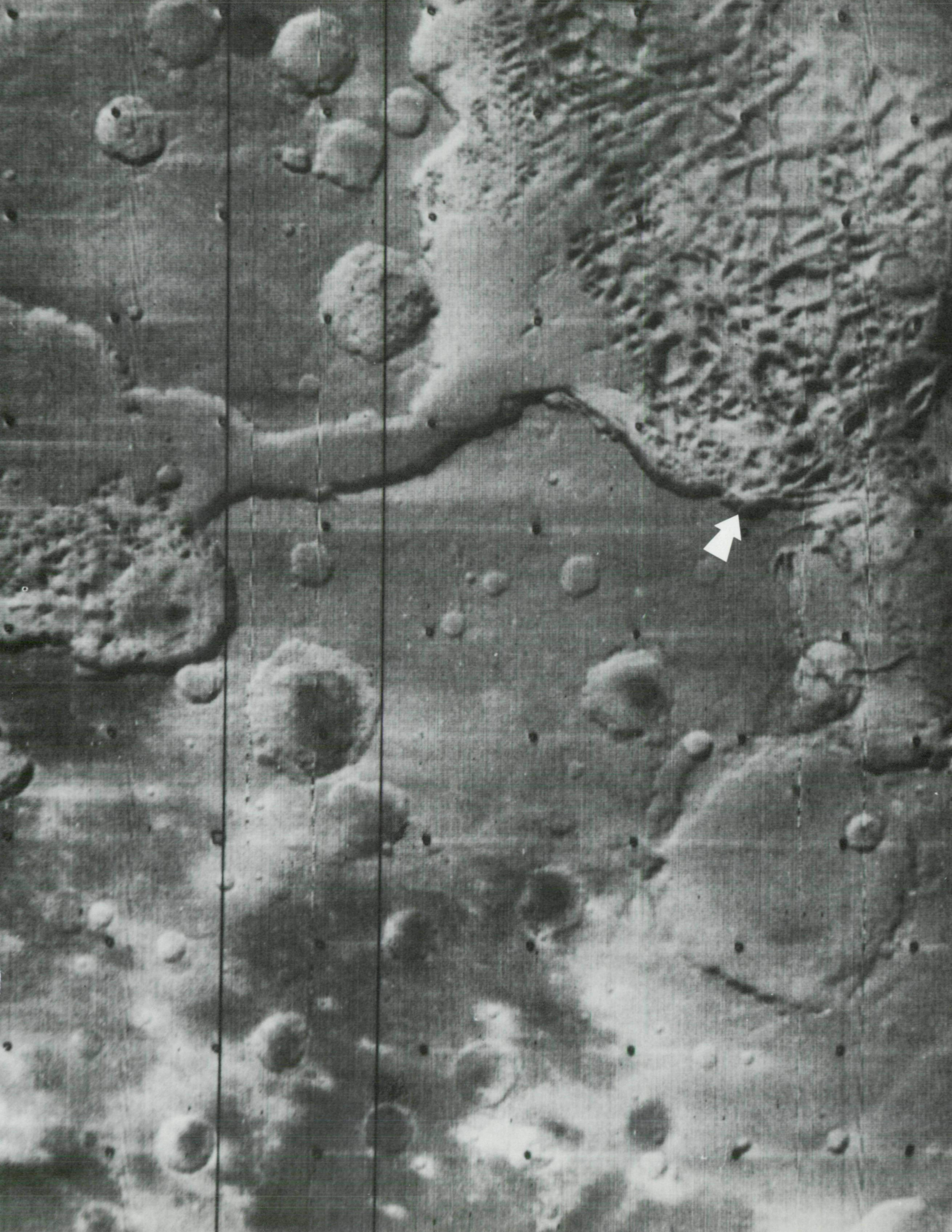
Association of chaotic terrain (upper right, facing page) with flat-floored steep-walled features that are characteristic of fretted terrain suggests some common genetic influences. Note *the arcuate slump blocks at the lower edge of the chaotic area* (arrow). The flat-floored chasm leading to the left may have been modified and widened by the recession of walls as a result of undermining or it may represent a channel carved or modified by a huge flood which burst forth from the area of chaotic terrain.—R. P. Sharp

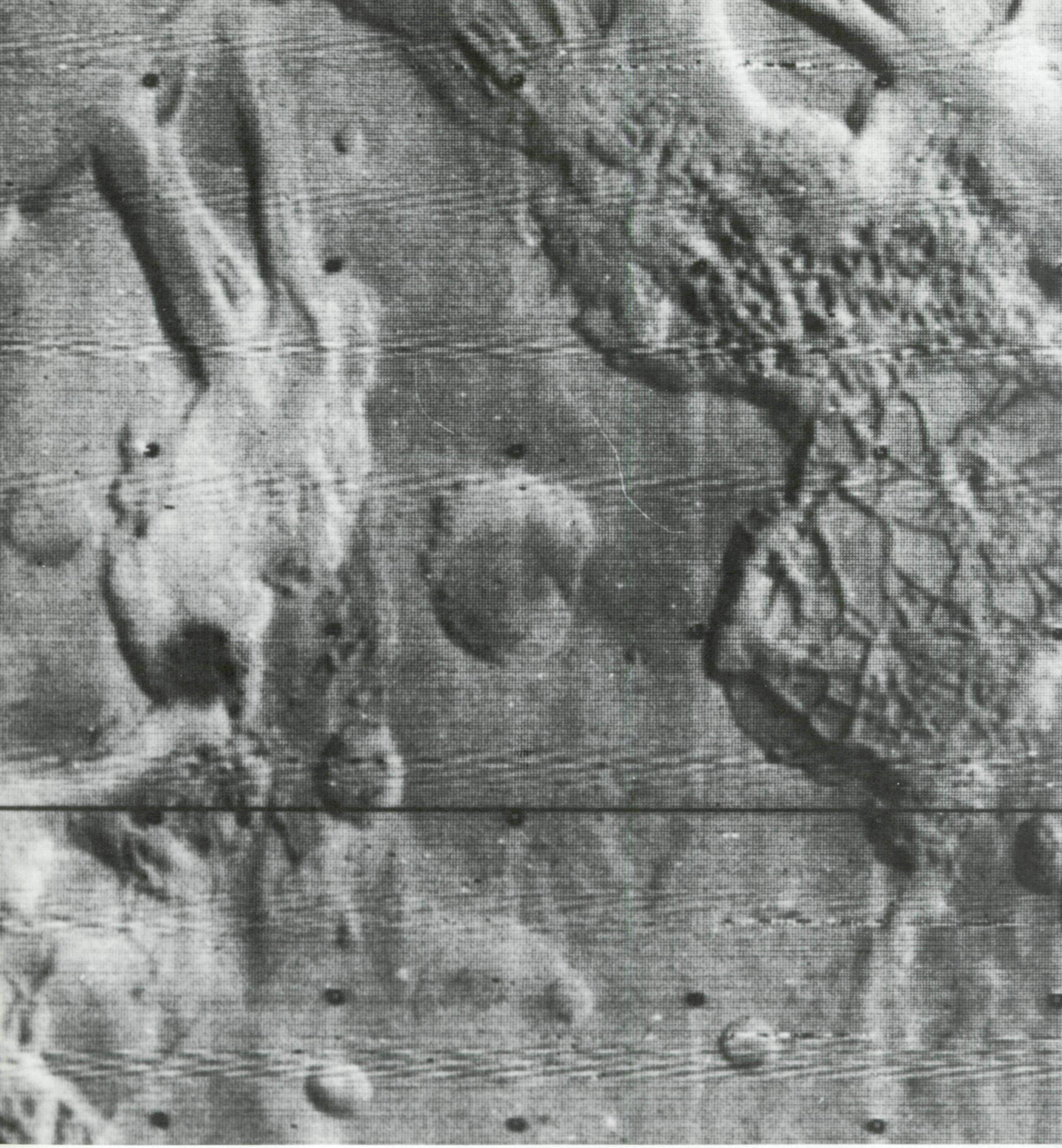
(1°S, 20°W; IPL 7059/162910)
(4°S, 20°W; IPL 1411/212107)

Views of chaotic terrain (below), formed by the collapse of an old crater upland when its underlying support was withdrawn. In the top photo, a broad, seemingly scoured channel can be seen emerging from the chaotic area in the upper right corner; the photo at bottom shows a close-up view of the broken blocks in the right central part of the top photo.—R. P. Sharp





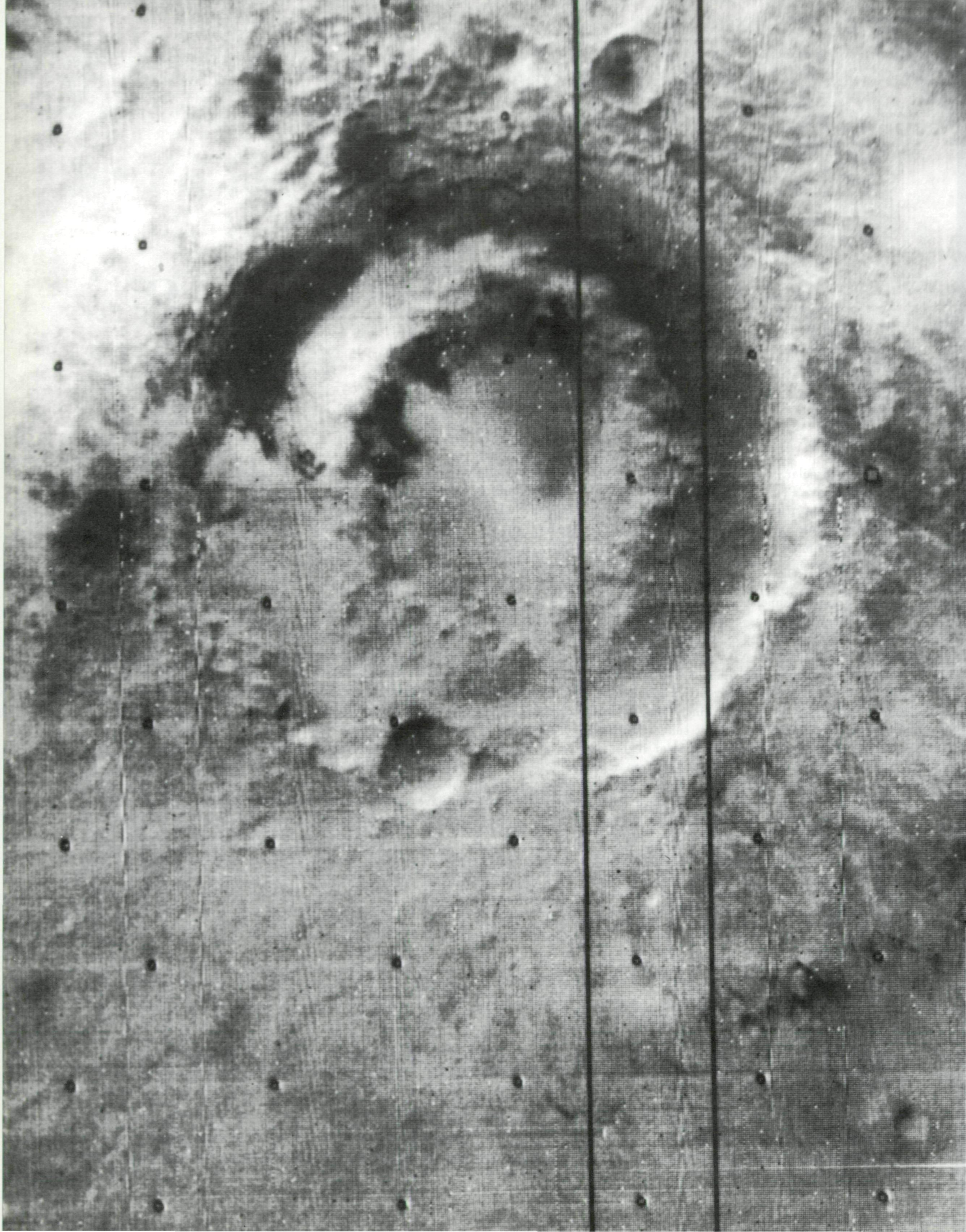




(3°N, 28°W; MTVS 4203–60)

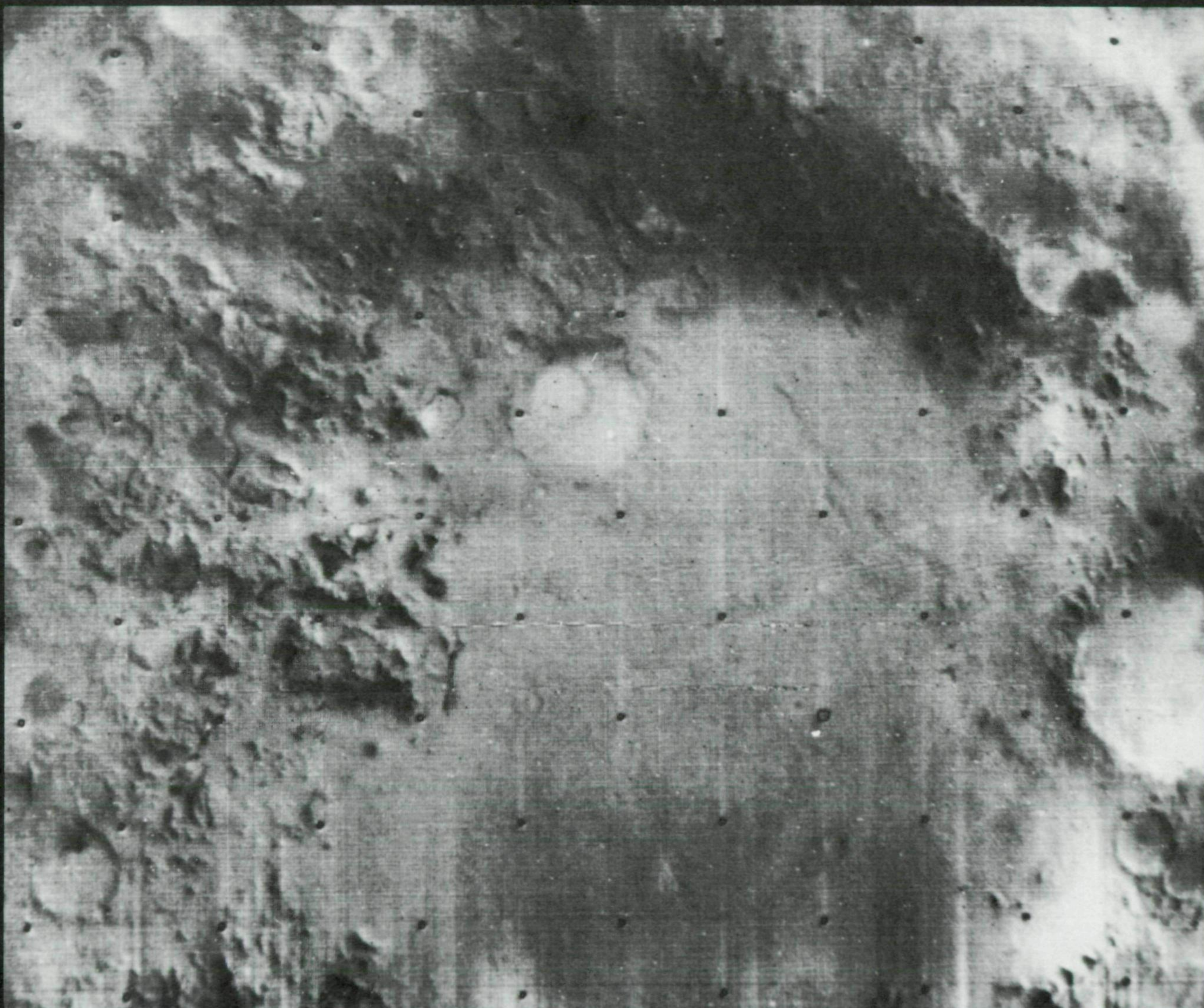
This moderately cratered surface extends over several thousand square kilometers. Three areas shown in this photo consist of complex mosaics of broken surfaces ranging from over 15 km across down to the resolution limit of several hundred meters. The massively fractured and slumped chaotic terrain generally lies below the level of the surrounding older surface. Large channels originate in the chaotic terrain area and extend many hundreds of kilometers northward. The chaotic terrain and channels may

have resulted from removal of materials in the subsurface with consequent collapse of overlying strata. Perhaps some form of ground ice melted, and the resulting liquid drained away forming the large channels. However, physical/chemical processes needed to produce such large quantities of ground ice, and later to supply large amounts of local heat to melt the ice in a very short time span, are not recognized topographic/geologic processes.—H. E. Holt



(53°S, 81°W; IPL 406/1927722

The double-ringed basin Lowell (left), 200 km in diameter, is most probably of impact origin. Sharp-textured ejecta attest to its relatively recent formation. In comparison to craters having single rim crests and multiringed circular basins, this crater is intermediate in diameter and in number of rings. It shows what many older, degraded features once looked like.—D. E. Wilhelms



(46°S, 44°W; MTVS 4139–9)

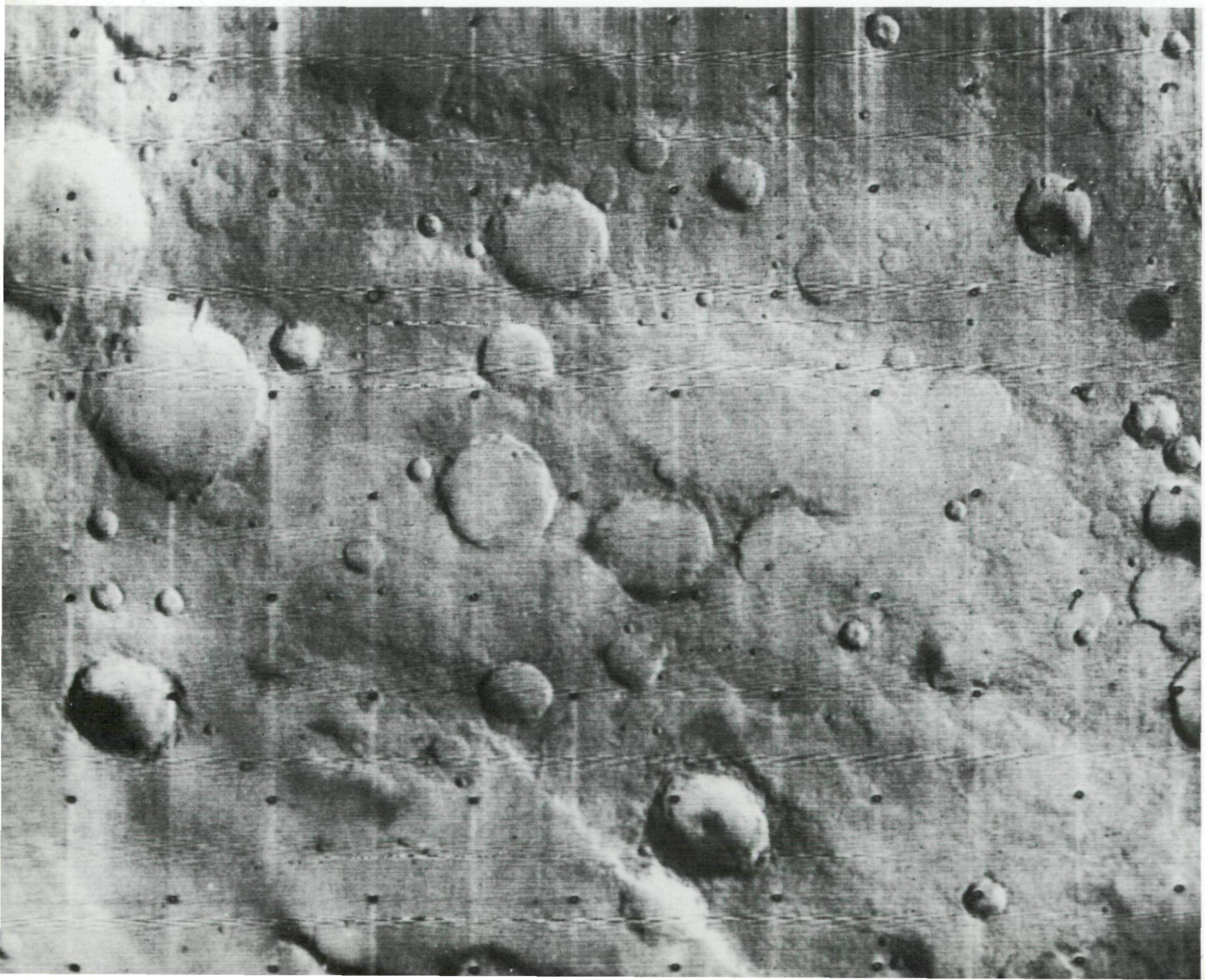
This smooth plains area is the northern half of Argyre Planitia and is about 800 km across. Careful study of this and adjoining photographs reveals concentric rings of high, rugged terrain around the plains, similar to the multiringed circular basins seen on the Moon.—D. E. Wilhelms

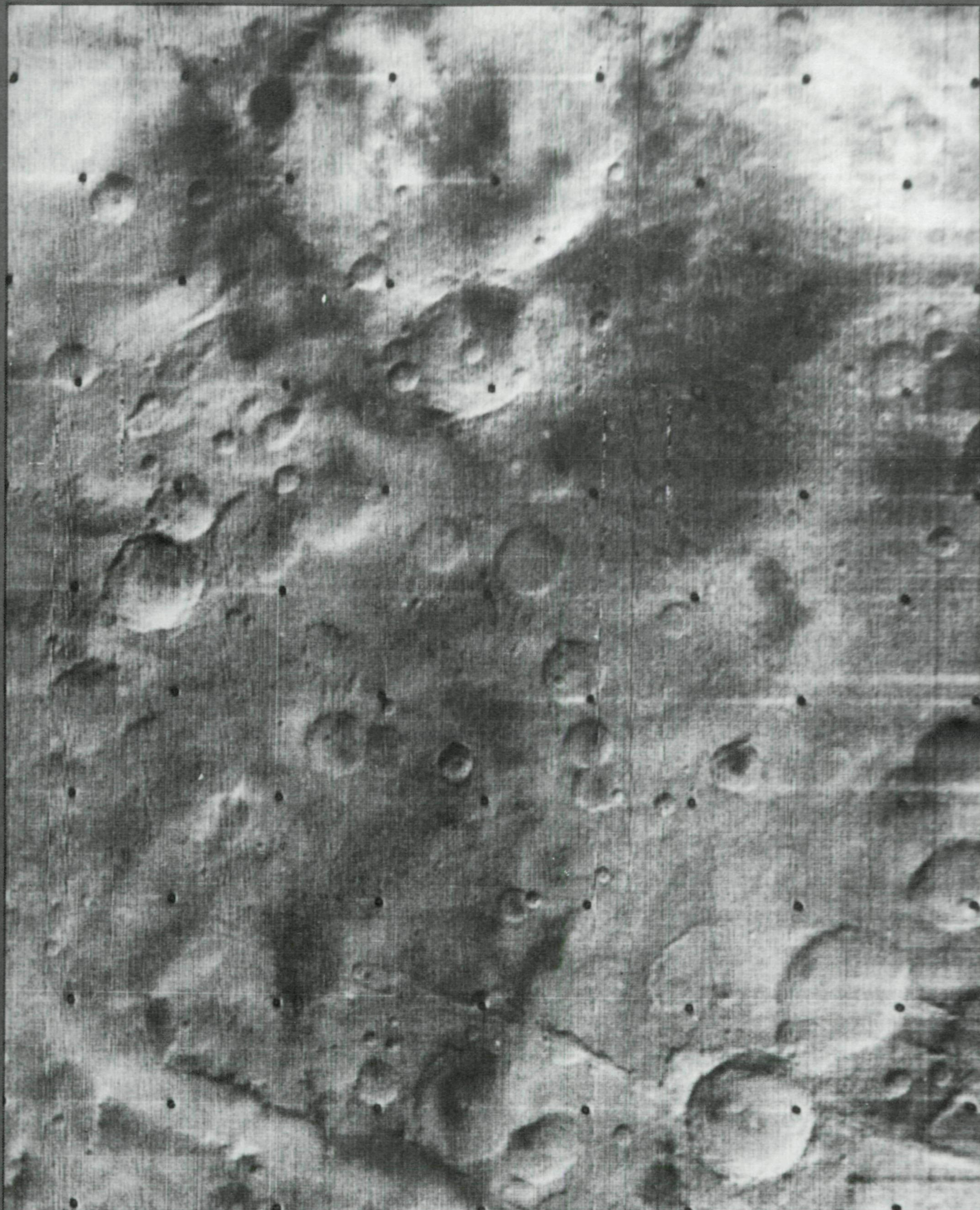
(16°S, 350°W; MTVS 4287–24)

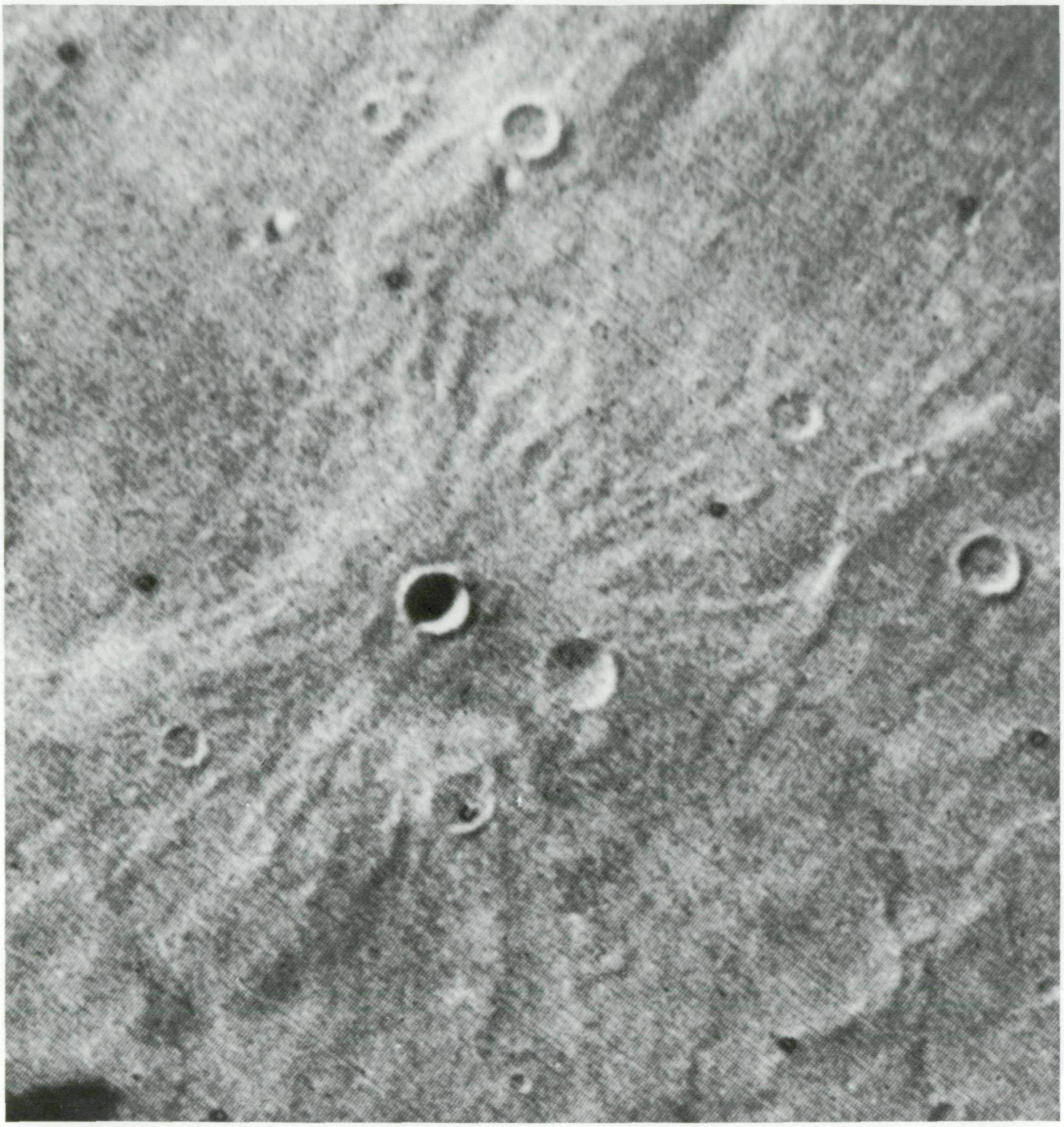
Typical cratered terrain (right) has both old, smooth-rimmed craters, and younger, sharp-rimmed ones. The large one at the top is 165 km across, with a conspicuously flat floor and slumped walls. Note the small doublet craters at lower left with central peaks.—M. Gipson, Jr.

(5°N, 250°W; MTVS 4194–60)

This cratered terrain (below) also shows lineated features made up of plateaus and troughs. They align radially with the Isidis basin, which is outside this image toward the northwest.—D. E. Wilhelms







(38°N, 343°W; MTVS 4210–66)

The sharply defined little crater in the center of the photo above is relatively young, as attested to by its bowl-shaped floor, raised rim, and well-preserved, ray-like ejecta blanket. Its diameter is 3 km.—J. W. Allingham

(23°N, 290°W; MTVS 4183–90)

A combination of densely and moderately cratered terrain (left) also includes populations of old craters and those of moderate age. Scale of this photo is about 450 km across the top. Two parallel troughs occur at the bottom.—D. E. Wilhelms

(3°N, 304°W; IPL 1764/235027)

A continuum of crater types (above) is revealed in this picture, ranging from the subdued, knicked one at bottom to the sharp-edged, relatively young one at top, with its ejecta blanket and small central peak.—D. E. Wilhelms

(38°N, 335°W; MTVS 4212–66)

Impact origin (right) is probable for this 15 km crater. The hummocky texture of its ejecta blanket suggests that little erosion has occurred since its formation. Nevertheless sufficient time has elapsed for several kilometer-sized craters to have been produced in the ejecta. Many small craters can be detected in this picture down to the limits of resolution of several hundred meters.—D. E. Gault

9
Wind-Shaped Features

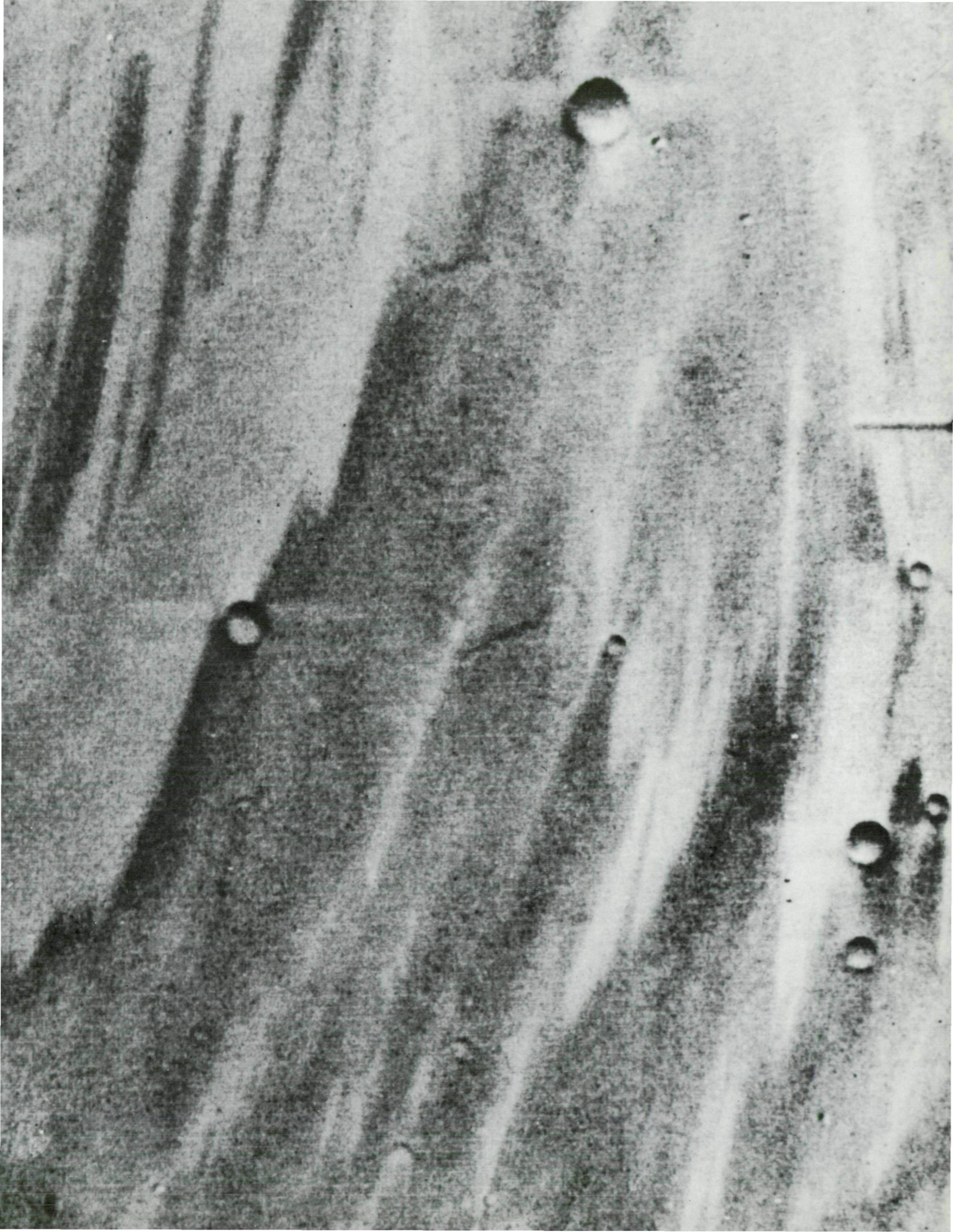
Mariner 9 convincingly demonstrated that wind is the dominant agent of erosion and sedimentation on Mars. In addition to the great dust storm of 1971, a wide variety of features that can be ascribed to wind activity were found. Unlike craters on the Moon (which lacks an atmosphere) the craters on Mars show the effects of both eolian erosion and deposition. Most craters tend to have flatter floors and less distinguishable surrounding ejecta blankets. Others appear to have been once buried and are now being exhumed by wind action. The equatorial regions of Mars appear to be areas where wind erosion predominates over deposition. This can be seen in numerous examples of streamlined canoe-shaped hills, fluted cliff faces, along with multitudinous parallel grooves on the surface of the flat plains. Similar appearing features are found only in the most rainless and wind-swept deserts of the Earth. (See "Similarities: Mars, Earth, and Moon.") The midlatitude and polar regions appear on the other hand to be areas where deposition of fine windblown material predominates. These deposits produce vast almost featureless plains that bury earlier craters and volcanic flows.

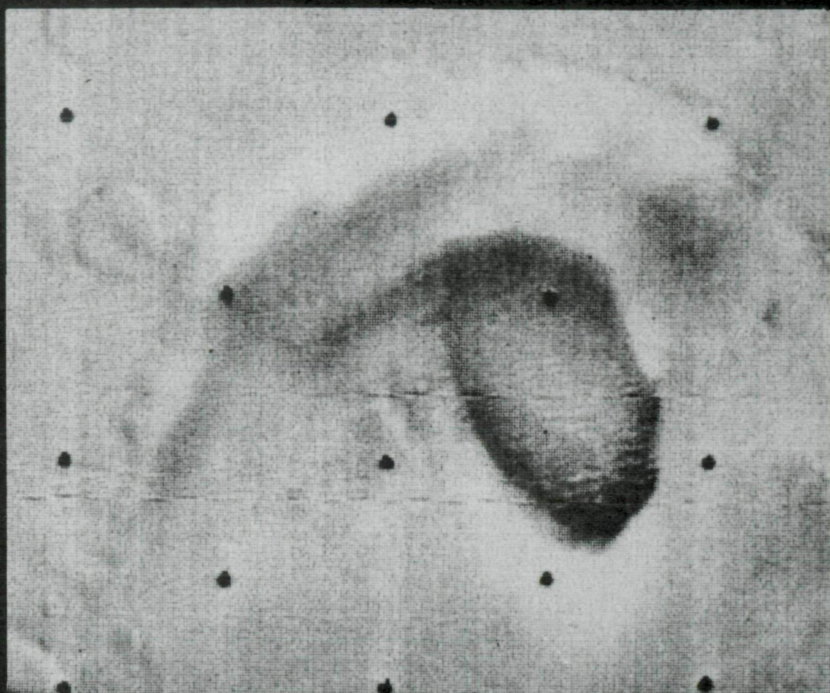
The changes in the surface markings of Mars have been a puzzle to telescopic observers for generations. Many elaborate hypotheses have been invented to explain these in terms of vegetation, volcanic activity, or chemical changes. Mariner 9 has shown that almost all the surface markings can be explained by wind activity. Many of the abundant light and dark streaks are associated with craters and other topographic features. These frequently merge into broader mottled patterns that at the telescope would have appeared to be continuous dark patches.

During the Mariner 9 mission some of the streaks actually changed shape and position indicating that they are superficial. (See "Changing Features.") One explanation is that the light areas are zones of deposition of recent dust and fine sand. The dark areas are zones of somewhat coarser and darker material where dust and sand have been removed or were simply not deposited. The same situation prevails in terrestrial deserts in the lees of topographic obstacles. Some of the dark areas in the floors of craters, on the other hand, proved to be large dune fields, further convincing evidence for the dynamic role of the wind on Mars. We now know that the wind is currently sculpturing the surface of Mars, removing silt and clay from some areas and redepositing it in others. As will be seen in other sections of this book, fluvial and glacial activity also have taken place. Thus primarily because of its atmosphere, however tenuous, Mars as had been surmised from the early telescopic observations to more closely resemble the Earth than does the Moon.—J. F. McCauley

(11°N, 283°W; MTVS 4186–69)

Dark and white streaks on the slopes of Syrtis Major Planitia. Viewed telescopically, the surface of Syrtis Major Planitia is dark, and has an eastern variable edge, whose lateral variation is enhanced by seasonal albedo changes. On Mariner 9 images, this dark region is resolved into a series of sub-parallel dark and white streaks, which extend several hundred kilometers. In this high resolution picture (40 km wide) taken by the Mariner 9 camera on January 30, 1972, a few weeks after the end of the 1971 dust storm, dark streaks extend from craters and unresolved point obstacles which protrude above an otherwise smooth surface. The small streaks extend as many as 50 crater diameters beyond the crater obstacle, and invariably flare in an easterly direction. The wider and nearly continuous dark streaks in the right of the picture extend from a large crater located outside the image. These dark streaks resemble the dark wind shadows formed in the lee of obstacles, particularly downwind from the slip face of transverse dunes (barchans) in terrestrial deserts, where turbulent eddies in back-sweeping motion remove light-toned eolian sand from a darker (and coarser) desert pavement. At the same time, sand saltates and creeps away downwind from the barchan horns. Both processes are concomitant on the Earth, and so they are on Mars. In support of this assertion is the digitate or serrated outline along the edge of the widest white streak in the image. The white "teeth" along this irregular contact between white and dark streaks point the same way as the flares in the dark streaks. They resemble the front of a sand sheet advancing over a barren terrestrial surface. The overall pattern of light and dark markings is confidently ascribed to the work of unidirectional, westerly winds.—M. J. Grolier





(47°S, 330°W; IPL 267/220940)
(47°S, 330°W; MTVS 4228–15, 4264–15, 4264–19)

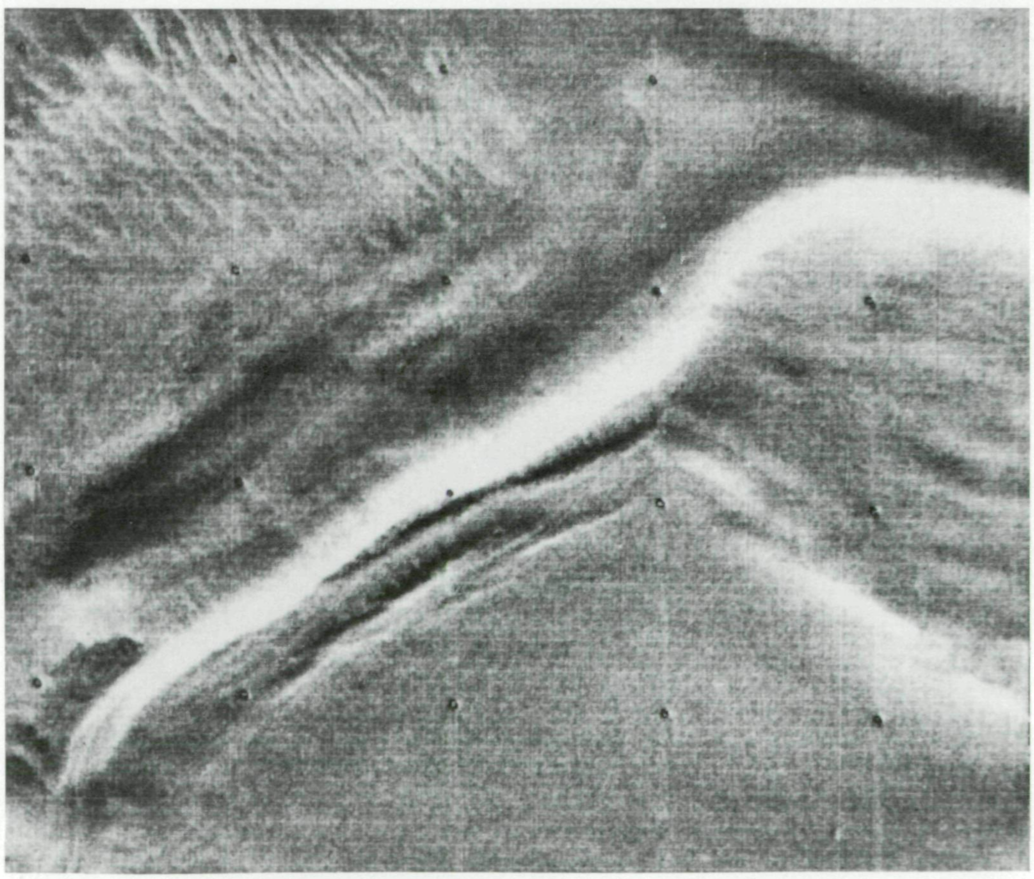
A dark zone in the floor of a crater near Hellesponti Montes is seen in the low resolution photo above. Similar appearing dark splotches appear in the floors of many Mars craters. The high resolution photomosaic at left reveals that the dark zone is an elliptical dune field about 130 by 65 km in size. The dune field consists of series of subparallel ridges, 1 to 2 km apart, that closely resemble terrestrial transverse dunes. Many of the ridges appear to have rounded crests with similar slopes on either side. This suggests that although the wind here generally blows at right angles to the transverse ridges it may intermittently reverse its direction so as to even out the slopes on the windward and lee sides of the dunes. The unusually dark appearance on what appears to be the more windward side of the dunes may be concentrations of dark heavy minerals such as ilmenite and small dark lithic fragments. On Mars, concentrations of such heavy minerals may have become preferentially trapped in crater floors because of wind action.—J. F. McCauley

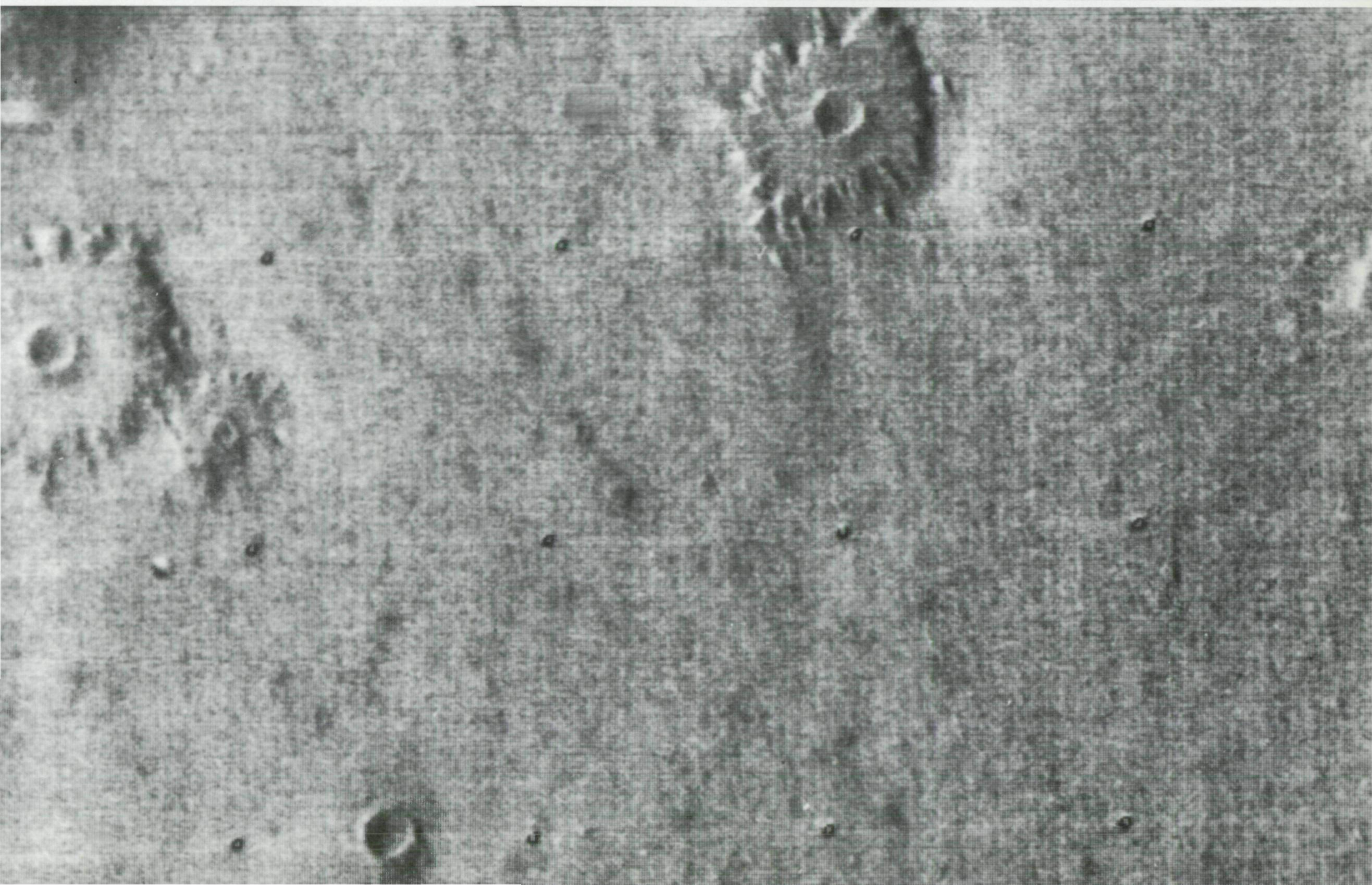
(38°N, 260°W; IPL 1433/210342)
(5°N, 152°W; MTVS 4294–28)

Differential erosion of two different types around probable impact craters. Top right, a sharp-rimmed, 20 km crater is encompassed by a radially and concentrically fractured rim unlike that seen around any lunar crater. Similar features are known to occur in the bedrock beneath the ejecta of terrestrial impact craters. This suggests that wind action has completely stripped away the original ejecta deposit exposing the shock deformed pre-crater surface. In contrast "pedestal" craters 1 to 2 km across, also different from any lunar crater, are seen below right. They are surrounded by sharp serrate scarps that coincide approximately with the boundary of what would be the continuous ejecta blanket of an impact crater. In this case the rubbly ejecta appear to have operated as a temporary "armor" acting to protect the surface on which it lies while the less resistant surrounding plain was being lowered by wind erosion.—J. F. McCauley

(71°S, 217°W; MTVS 4264–19)

Highlighted by frost, probable eolian features are seen in the specially processed high resolution photograph below. The features are most likely wind blown dunes of martian sand and dust. These dune-like features occur in craters located along the margin of the layered terrain in the south polar region. The features appear to be confined by the closed topography of the craters. The dunes are in a crater partly buried by layered terrain. Individual dunes are approximately 3 km apart. The area shown is about 40 km wide.—L. A. Soderblom



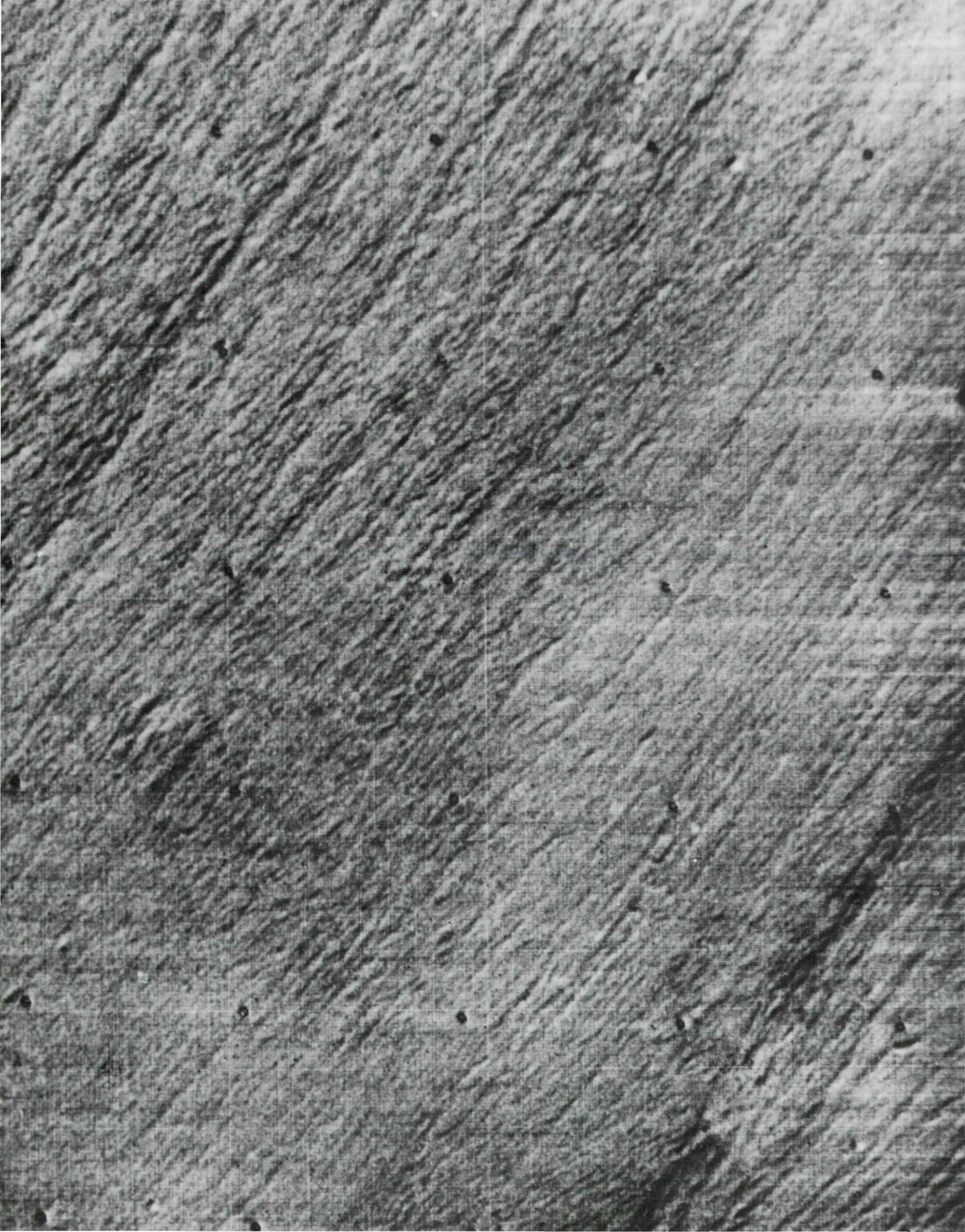


(87°S, 273°W; MTVS 4248–12)

Flutes and linear grooves (right) in the layered terrain exposed near Australis Chasma, south polar region. There is no polar cap shown here. Bedding is enhanced by the contrast between the light and dark layers exposed in steep bluffs, and the sides of the prominent ridge in the eastern part of the area. The short, finely structured striations in the bluffs stand out in contrast against the smooth surfaces of terraces and hollows, which are perhaps mantled with wind-blown material. Striations in the bluffs and wider flutes on gentler slopes are parallel, and best developed on south-facing slopes. A hill in the center of the image is grooved at one end, and beveled at the other end, much like some terrestrial yardangs are. The erosional pattern suggests that wind erosion, together with possible melting and sublimation of the underlying material, are the processes modifying this polar landscape. Scouring here is accomplished by winds originating near the South Pole (outside the imaged area).—M. J. Grolier

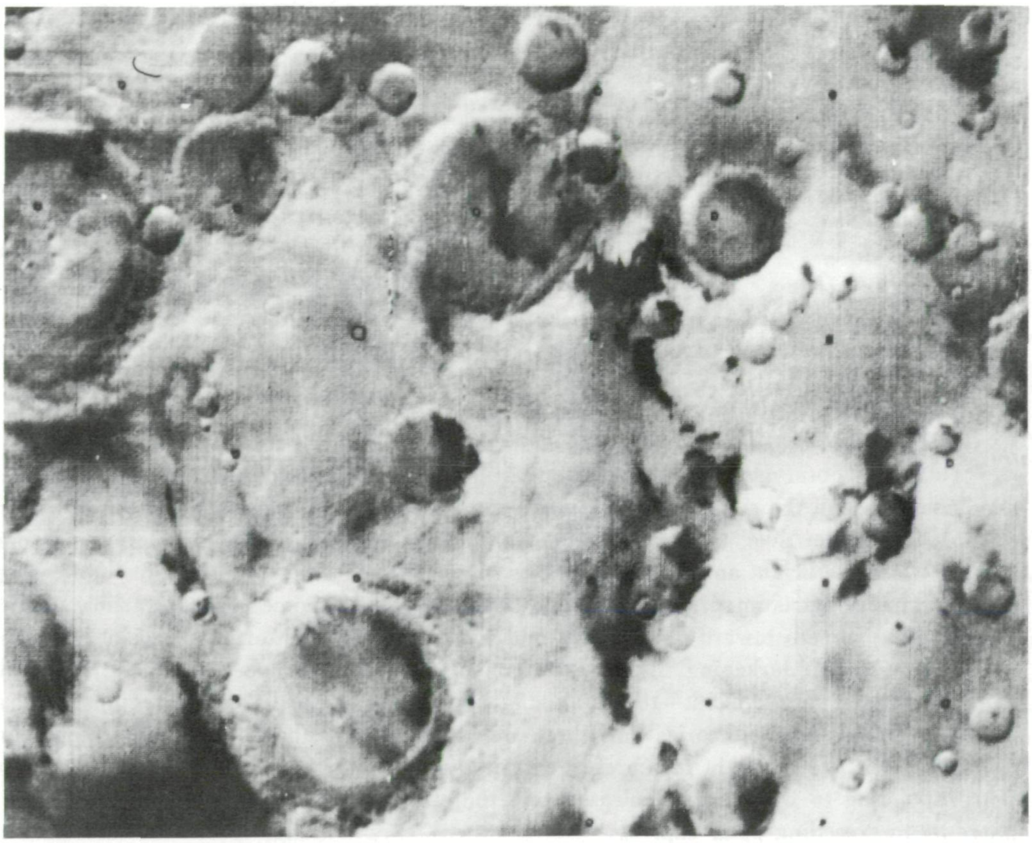
(74°S, 7°W; MTVS 4270–24)

Irregular pits and depressions near the south polar region are shown below in this high resolution photo. These depressions are generally characterized by flat floors and rather smooth walls. They are very similar to terrestrial deflation hollows formed by the plucking and scouring action of the wind. These landforms, like the other probable martian wind features described in this section, are many times larger than their terrestrial counterparts, the largest known of which are in the desert of north central China. Picture width is about 75 km.—J. W. Allingham



(5°N, 146°W; IPL 1596/212535)

Wind etched semi-parallel grooves occur on probable bedrock in the relatively smooth, uncratered plains of southern Amazonis. The width of the picture is about 40 km so that the alternating, streamlined ridges and grooves are typically about 200 m in width and tens of kilometers long. This pattern is probably controlled in part by bedrock fractures. Similar parallel scouring of homogeneous materials does occur, however, in the flat open parts of terrestrial deserts that are characterized by strong, almost unidirectional prevailing winds. On Earth similar appearing wind scour features are, however, many times smaller in size. Although the martian atmosphere is one hundred times less dense than that of the Earth, the wind velocities may be on the order of 200 to 300 km per hour. Thus the kinetic energies of particles moved by the wind will be many times greater and the erosional effect of sand blasting a far more important geologic process than on Earth.—J. F. McCauley

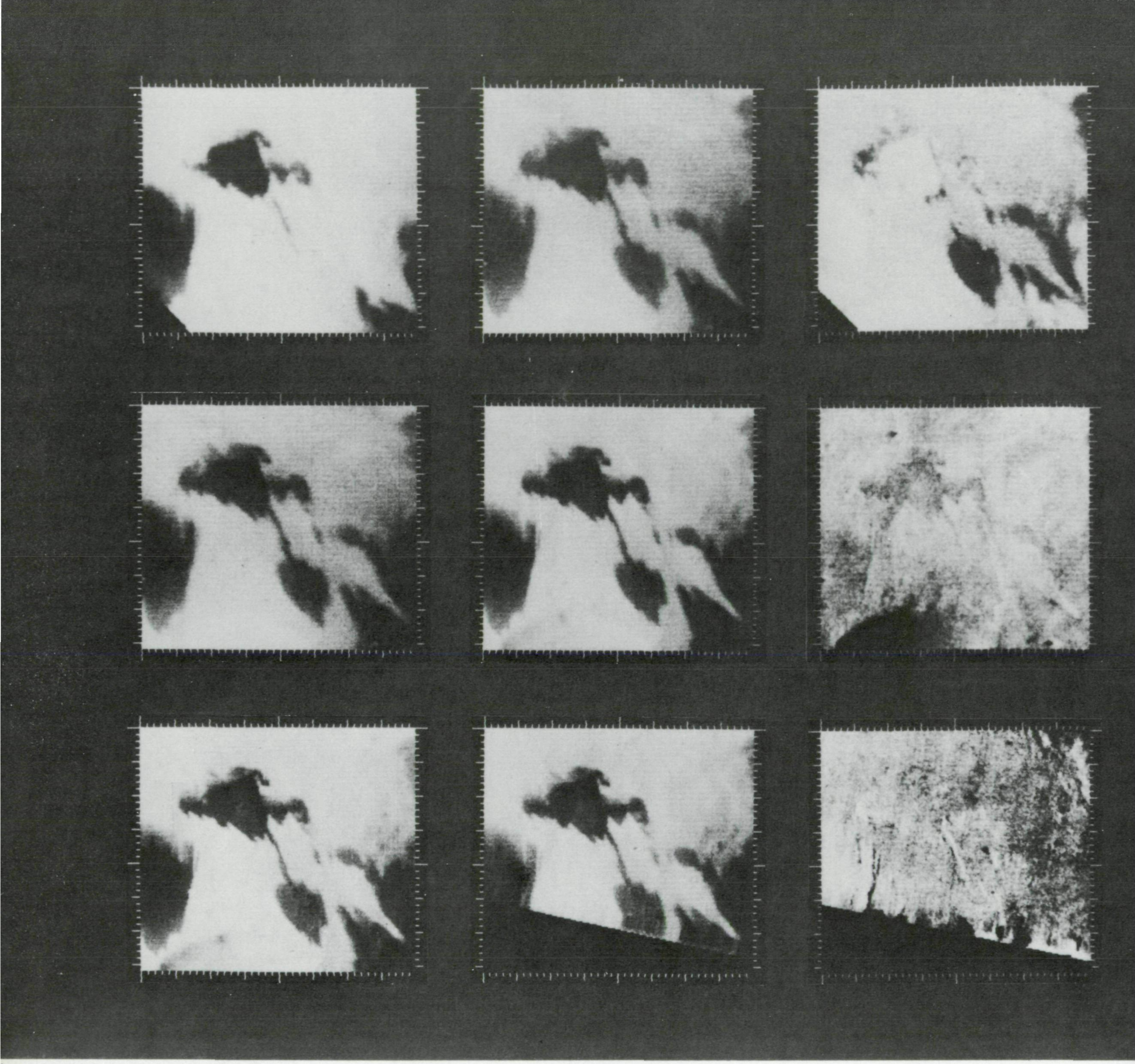


(70°S, 259°W; MTVS 4211–9)

A low resolution view of Promethei Sinus (above) shows an extensively splotched, cratered region near the south pole of Mars. This picture is about 450 km across. Variations in the appearance of this region have been reported by telescopic observers. Note that the dark crater splotches tend to lie on the downwind side of crater floors. A small crater near upper center is shown at high resolution on the facing page.—C. Sagan

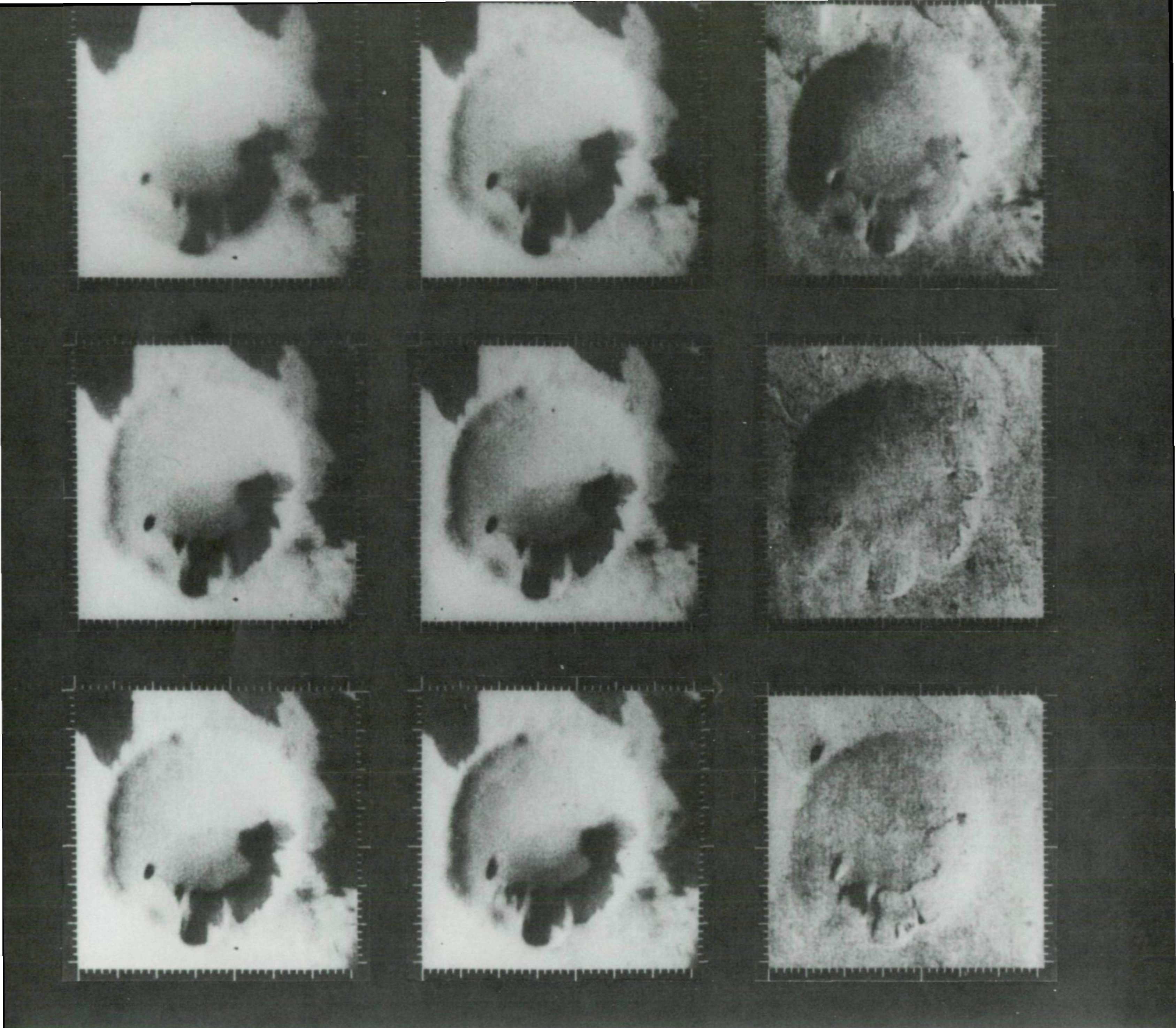
(70°S, 253°W; IPL 1418/143014)

This high resolution view of a region in Promethei Sinus was studied for surface variations during the Mariner 9 mission. The scalloped appearance of the albedo boundaries is characteristic of eolian phenomena—the inferred wind direction being at right angles to the scalloped edge. Variations in the crater splotch and in the leaf-shaped albedo marking just left of crater, most likely due to the removal of mobile material by winds, are shown on the following pages.—C. Sagan



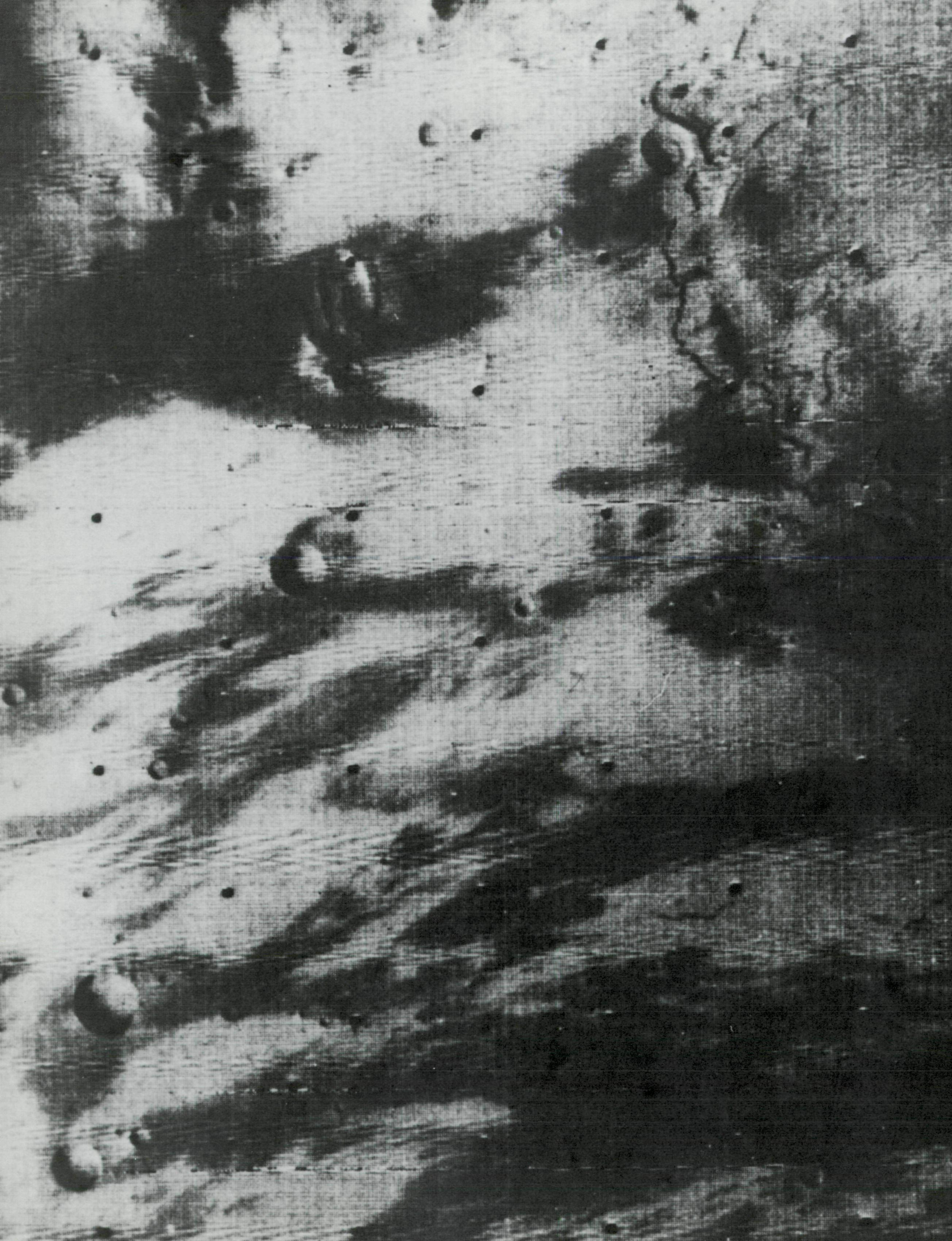
(70°S, 253°W)

The dark pattern changed from rev 99 (top left) to rev 126 (top center); rev 126 to rev 179 (middle row); and rev 179 to rev 181 (bottom row). After the images from each set (left and center) were similarly scaled and projected, then the two pictures were differenced, picture element by picture element. Images on the right show the differences (Stanford AIL Picture Product STN 9167:050609, 10, 11). Thus, it is possible to see the changes that had occurred between successive revolutions over the same area. Each frame is about 30 km across.—C. Sagan



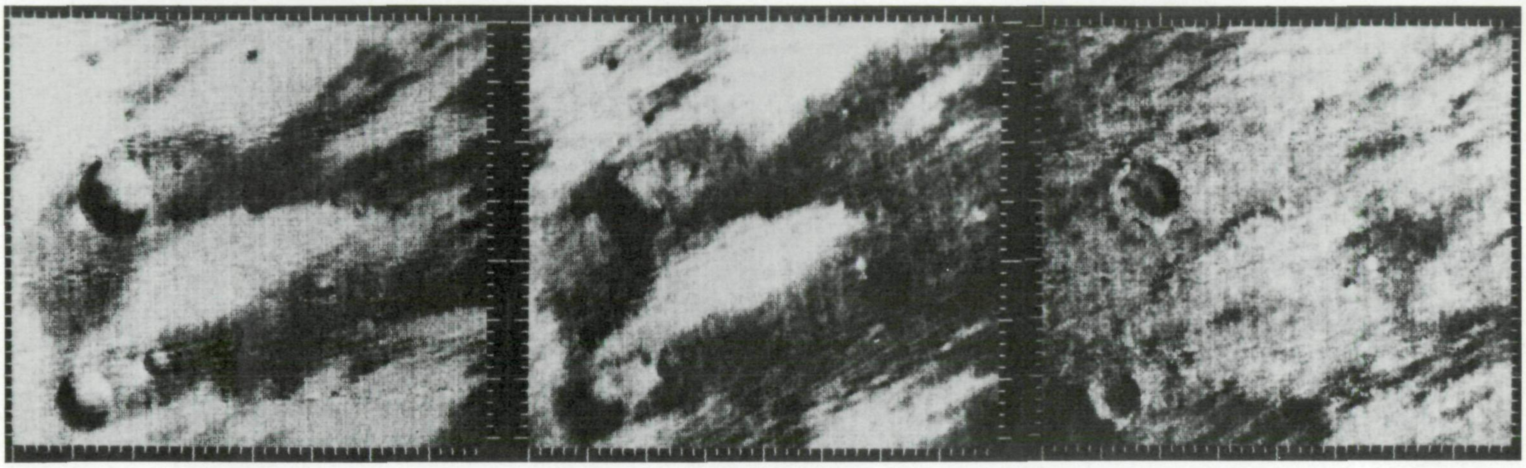
(70°S, 253°W)

These comparisons show changes in the crater splotch in Promethei Sinus. Differences between preceding views are shown at the right in each row; the left and center views are from (top row) revs 126 and 179; (middle row) revs 179 and 181; and (bottom row) revs 181 and 220 (Stanford AIL Picture Product STN 0173:061109, 10, 11). Since lighting and viewing conditions varied slightly, changes in shadows caused by topography cannot be successfully canceled out. Each frame is about 30 km across. —C. Sagan



(10°N, 283°W; MTVS 4186–69)

The eastern edge of the classical albedo feature, Syrtis Major, is outlined (left) by a concentration of variable dark streaks. The patchy, discontinuous character of these streaks is unique on Mars. This characteristic, as well as the tendency for the streaks to shed off tangentially in a common direction from topographic protuberances such as crater walls, suggests that they are produced by eolian erosion of extensive, but very thin, deposits of bright albedo material, resulting in the exposure of dark, underlying, wind-resistant formations. This low resolution view is about 370 km across. —C. Sagan



(10°N, 283°W)

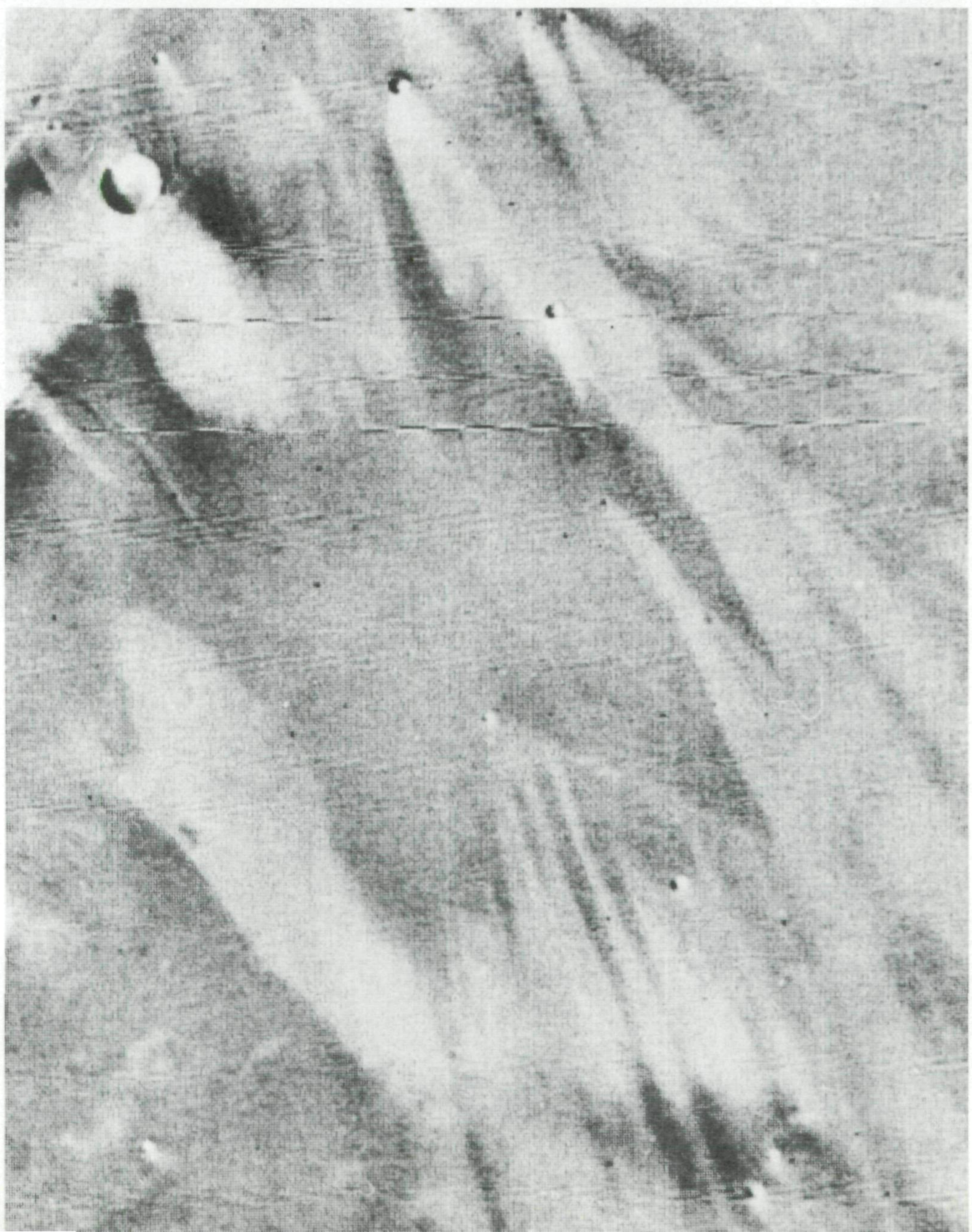
The gradual darkening of Syrtis Major (above) after the 1971 dust storm is revealed by Mariner 9 photography. The effect of the storm may have been to cover the area with a thin layer of bright dust. Subsequent winds, blowing predominantly west to east (the direction of the dark tails), scoured off this material, especially in regions where wind speeds are intensified by topography. The views are from rev 155 and rev 233; the image at right shows the difference of the two (Stanford AIL Picture Product STN 0164:041506). The area is about 130 km across, and corresponds to the lower left portion of the photograph on the facing page.—C. Sagan

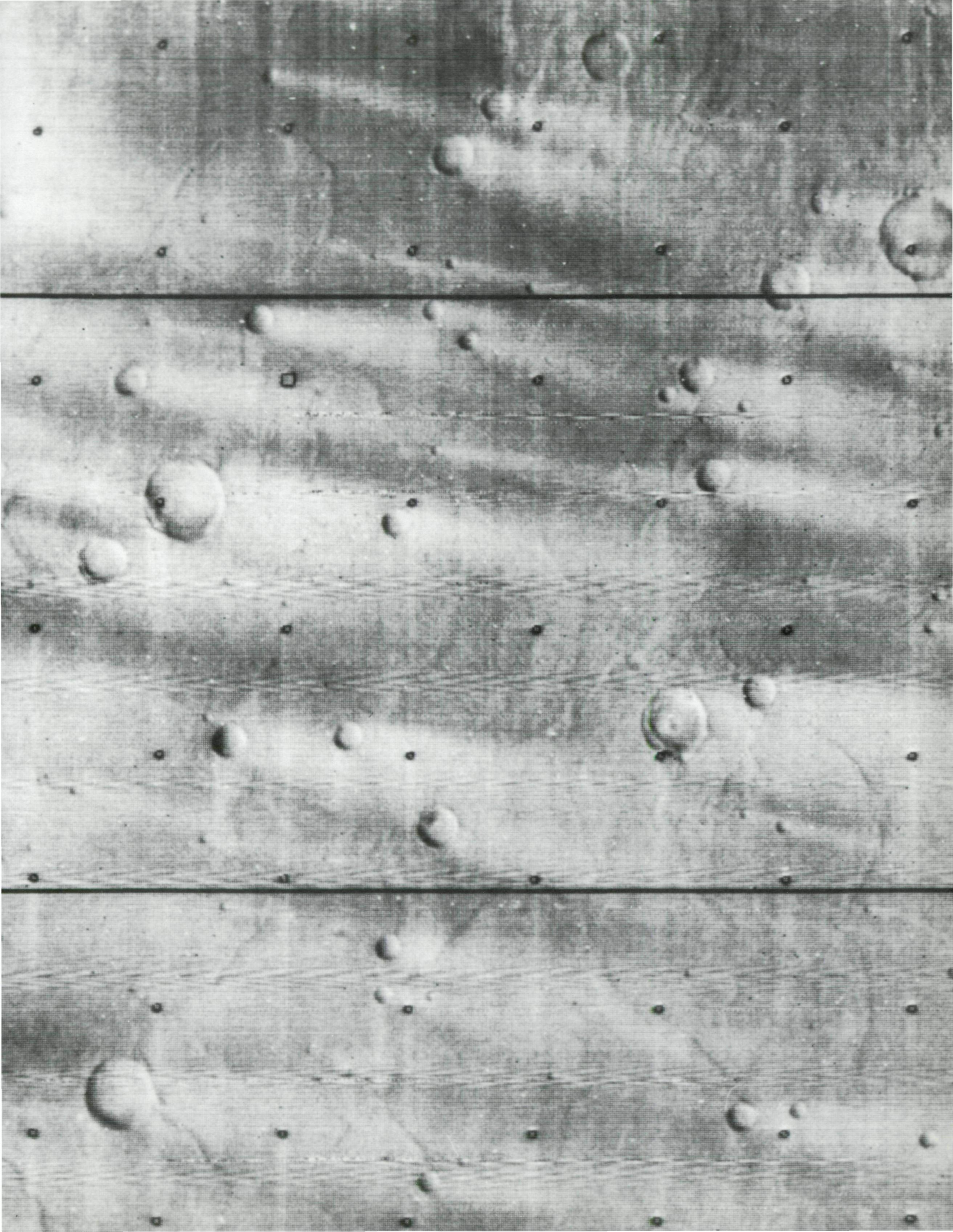
(23°S, 241°W; IPL 311/210101)

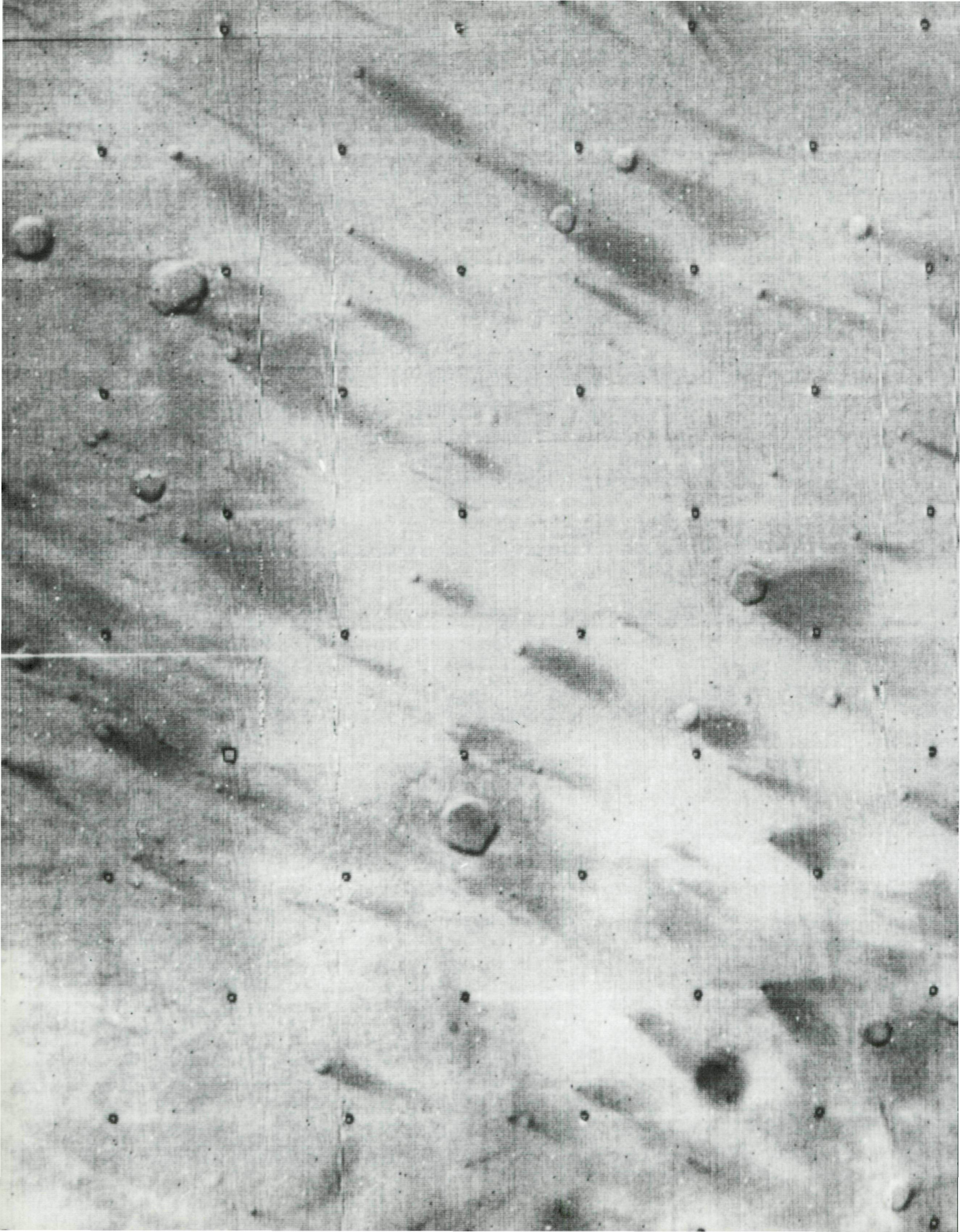
A low resolution view (right), about 400 km across, of a region in the Hesperia Planum shows numerous parallel, light streaks associated with craters. A credible explanation of such an array of long parallel streaks emanating from craters is that fine, bright dust, transported into craters in the waning stages of the dust storm, was subsequently blown out by high velocity winds having a prevailing direction. In any case the streaks must point downwind, and are natural wind direction indicators.—C. Sagan

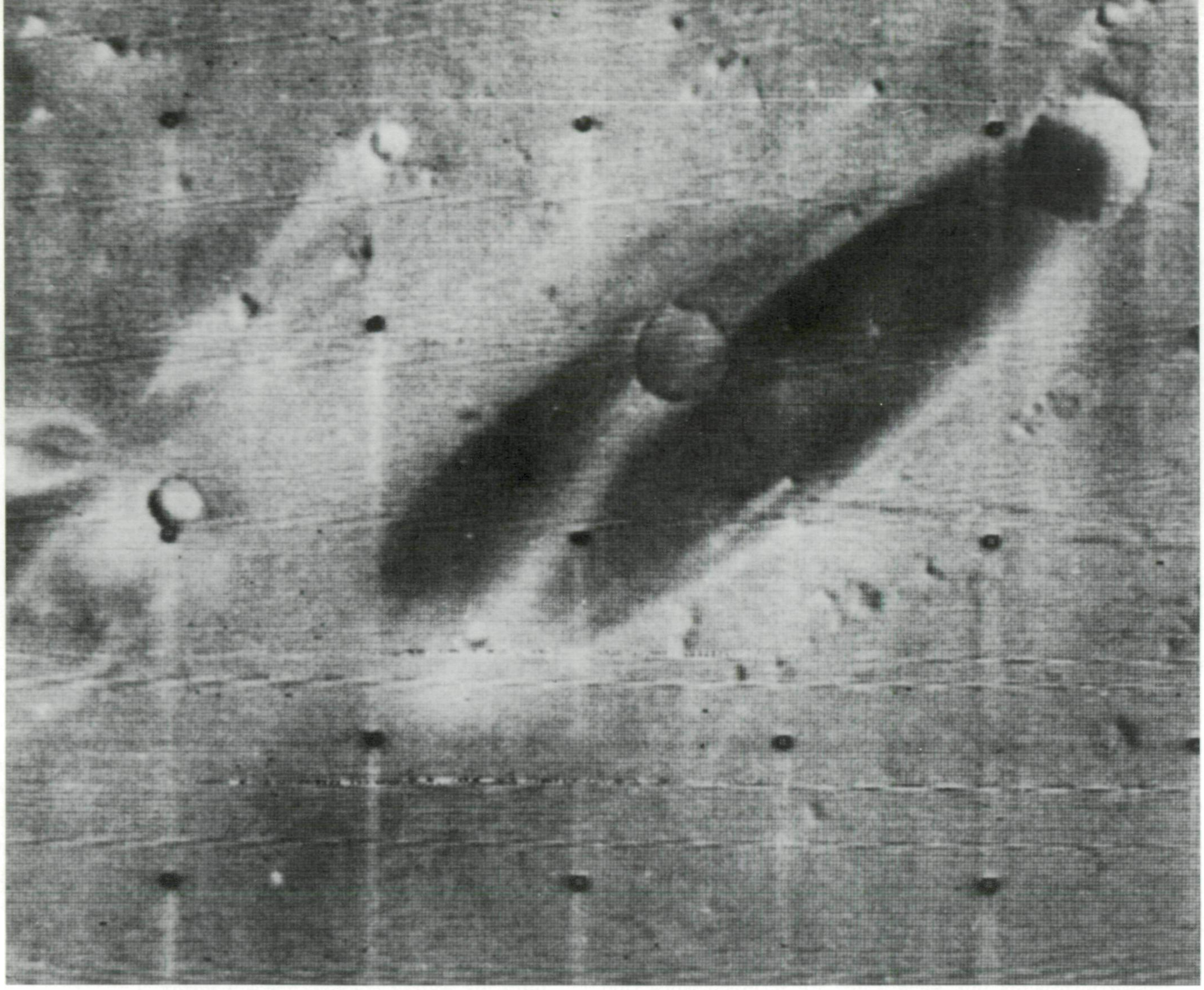
(10°S, 107°W; IPL 1108/150842)

An area in Tharsis (below), about 160 km across, characterized by an assortment of bright streaks showing strong evidence of an eolian streak stratigraphy. No variation in the configuration of these streaks was observed during the Mariner 9 mission.—C. Sagan







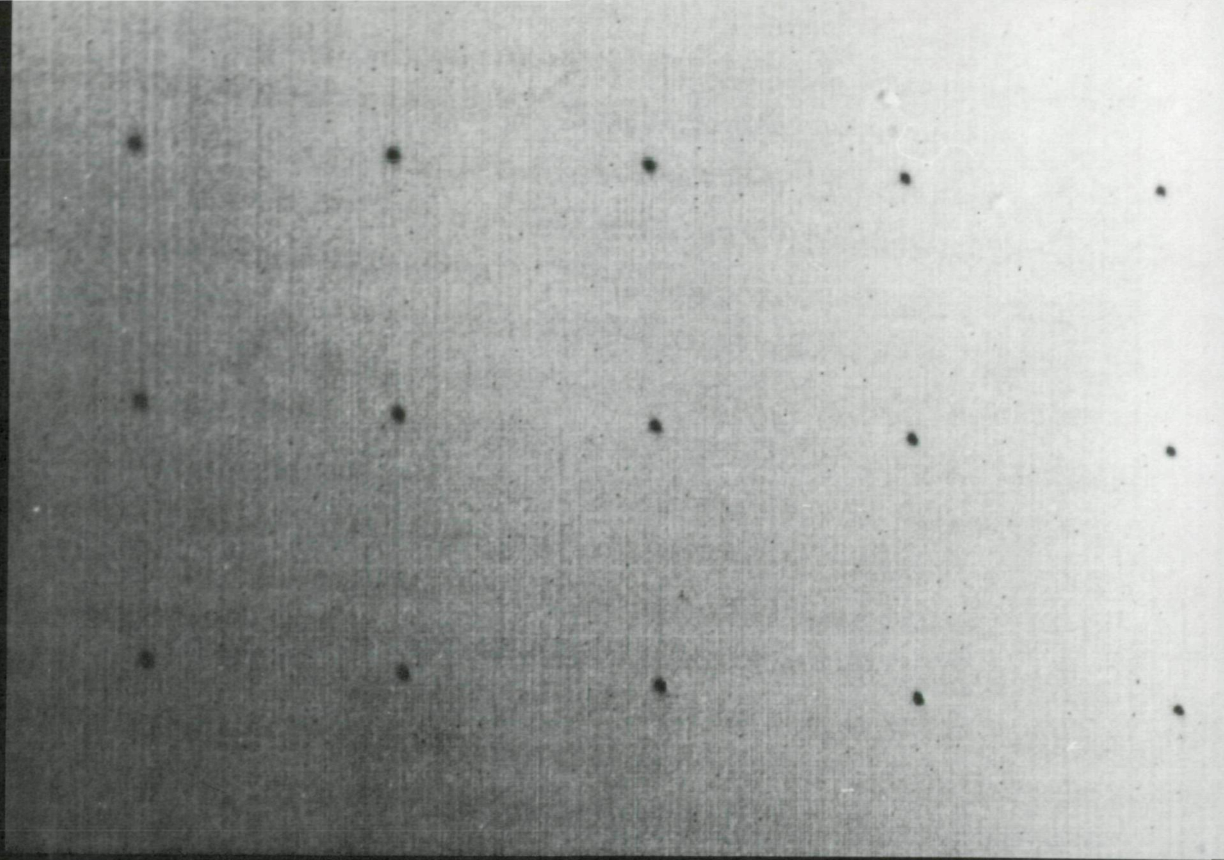


(9°N, 191°W; IPL 1612/173205)

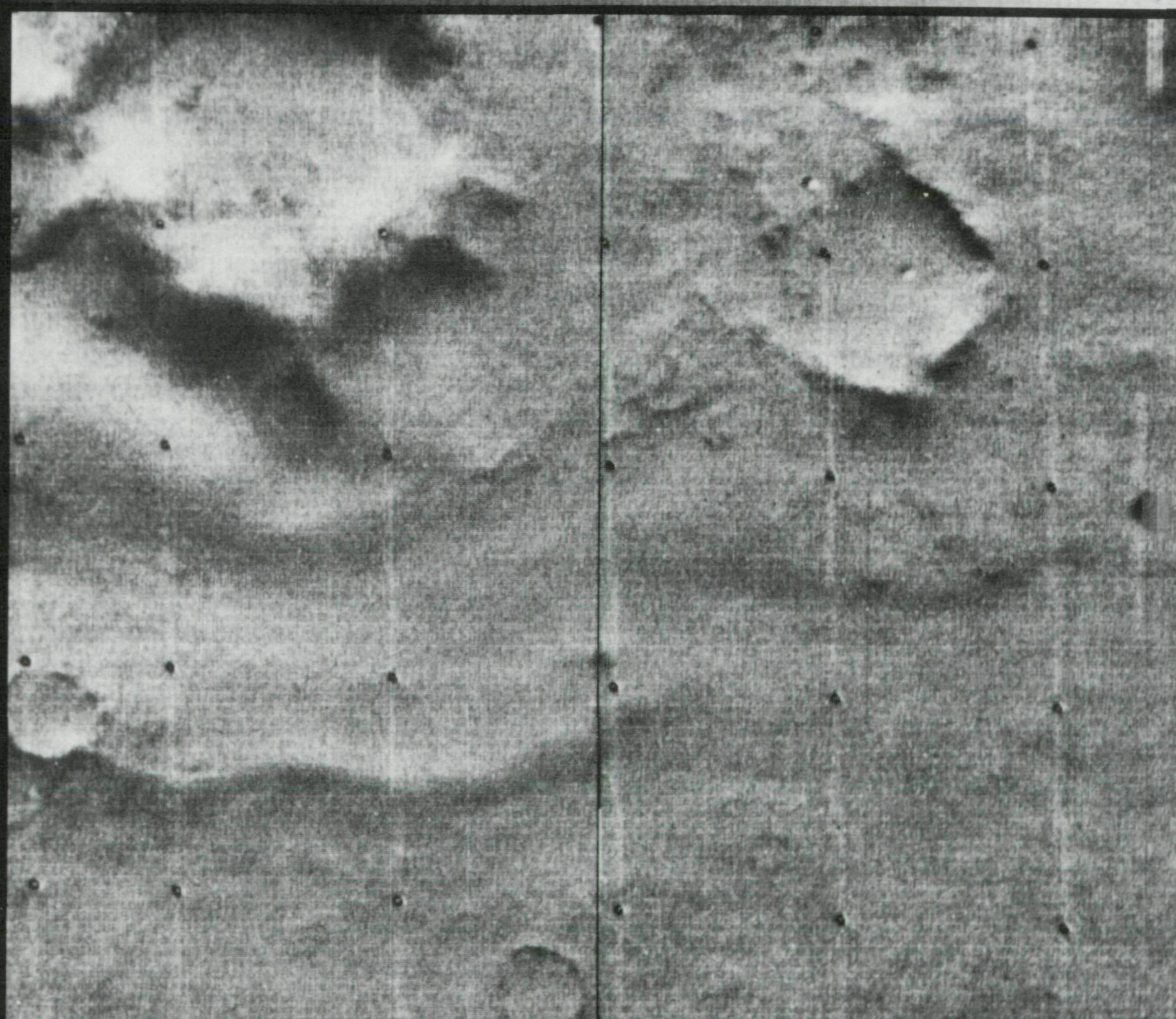
A region near Cerberus (above), about 245 km across. The prominent dark streak is probably depositional in character. An upwind crater can be interpreted as the source of the dark material which, carried downwind, produced the dark tail. In the process, a part of the rim of the smaller crater appears to have been covered by dark material, but there is also a shadow zone behind the smaller crater where no deposition occurred. There is a similar wind shadow behind a hillock near the lower right edge of the longer tail.—C. Sagan

(34°S, 62°W; IPL 1934/171817)

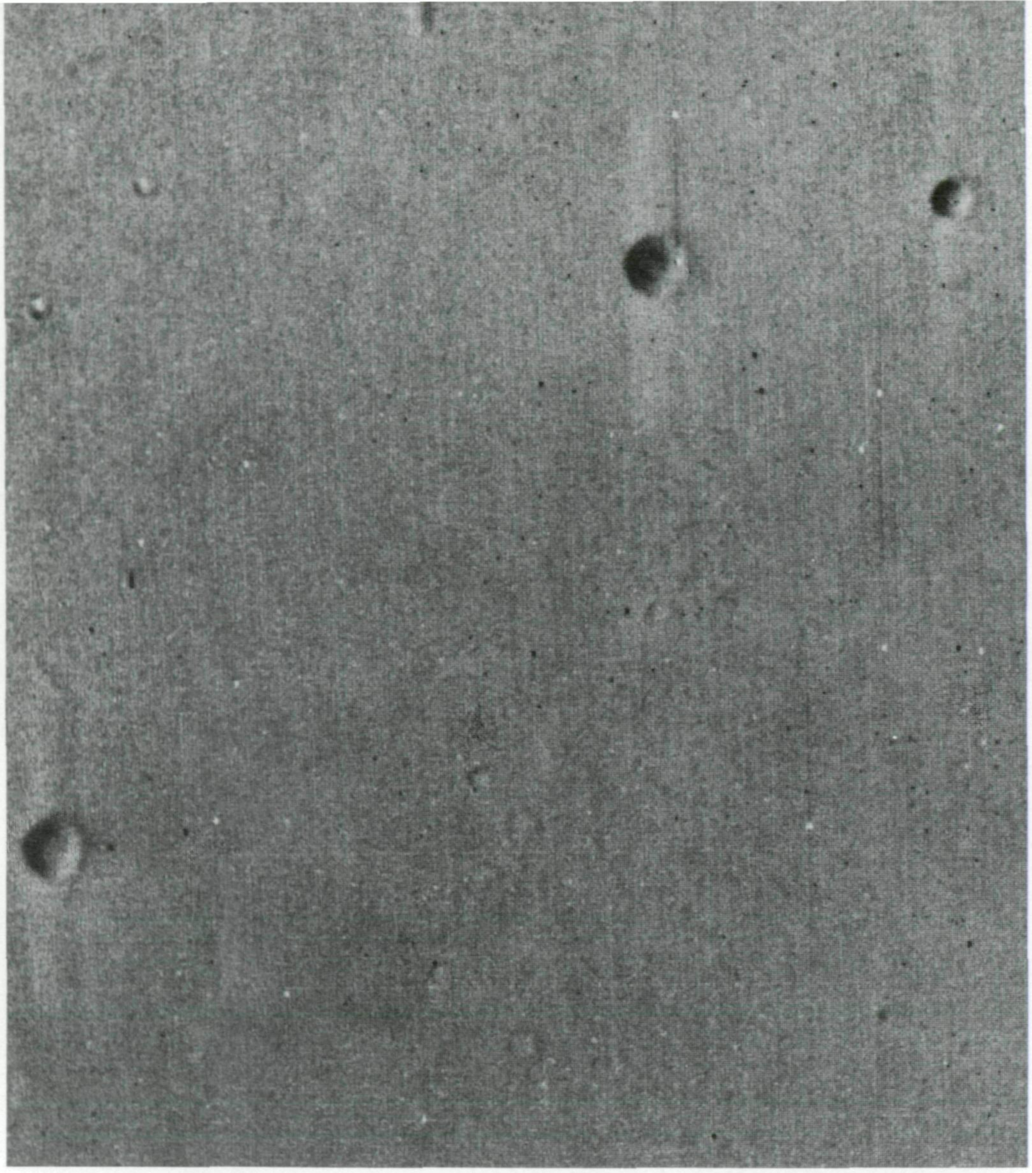
Dark crater streaks (left) stand out in this view of a region in Bosporos. This area is about 330 km across. Some of these dark streaks are more than 50 km long, yet remain very narrow throughout their length. Their common direction is that of the prevalent winds in the area.—C. Sagan



JAN 23, 1972



MAR 11, 1972



(14°S, 185°W; MTVS 4211–42)

Almost featureless even to the high resolution camera, this plain (above) in the center of the Amazonis basin shows only a few small, widely spaced craters. The largest crater in upper center is approximately 2 km in diameter and the smallest crater that can be seen is approximately 500 m in diameter. Except for three prominent craters, all craters appear very subdued possibly because of a haze layer or blowing dust close to the ground, or because the craters are partially or almost completely buried by thick wind-deposited sediments.—E. C. Morris

(46°S, 307°W; MTVS 4167–9)
(46°S, 305°W; IPL 1351/192301)

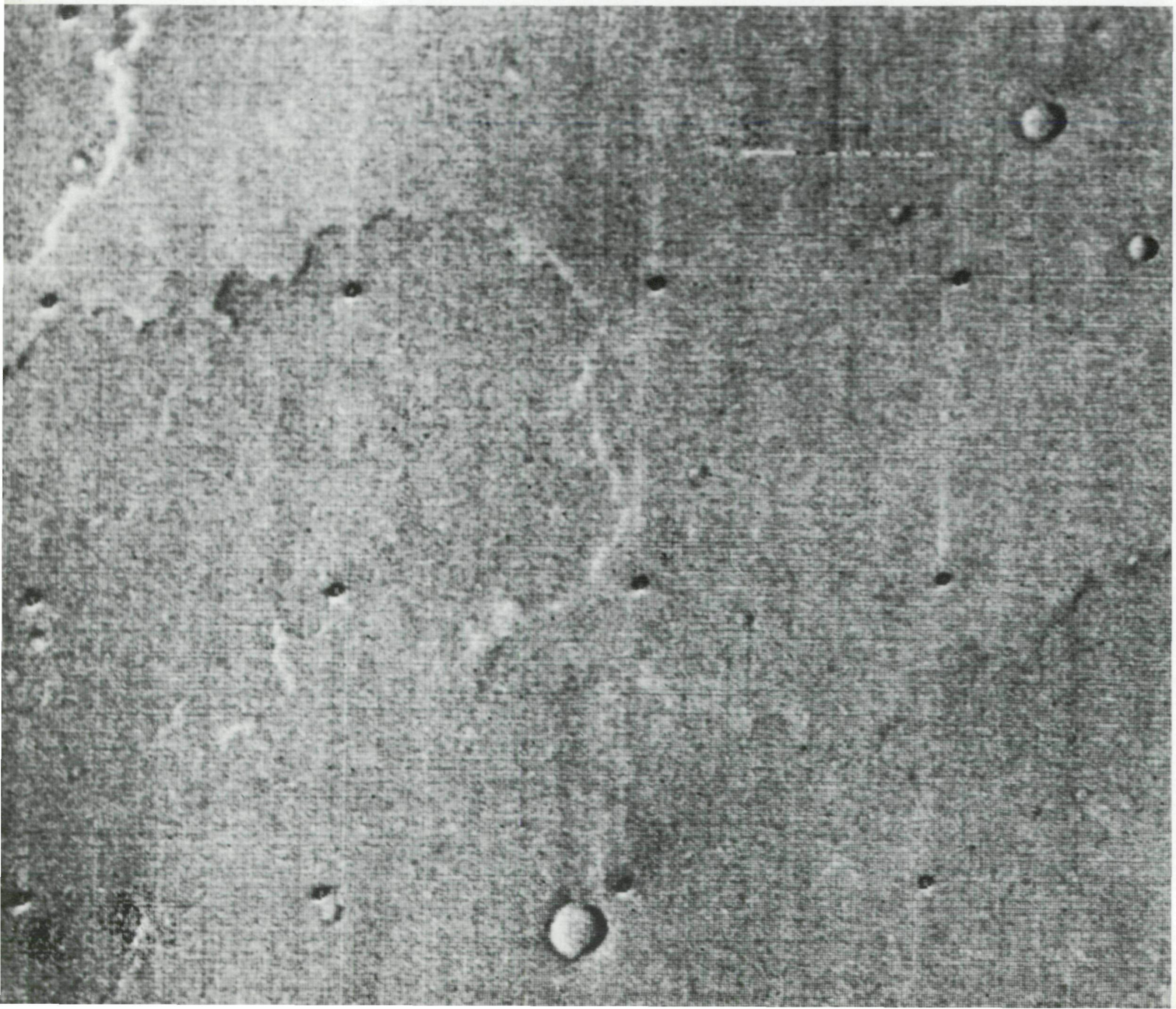
Smoothness can be the actual nature of the surface, or can be in the eye of the beholder, or in weather, or in the imaging system. Picture taken on January 23, 1972, shows an area of the Hellas Planitia (80 km) with no surface detail. (The faint circular outlines are artifacts in the imaging system.) Picture taken on March 11 shows ridges, craters, and other detail of the same area, indicating that a dust storm was active at the time the first picture was taken. Historically the Hellas basin has been the site of large dust storms as viewed telescopically and may have almost semi-permanent obscuration of its floor by blowing dust. It was probably fortuitous that the picture taken on March 11 was at a time when the atmosphere had cleared sufficiently to record the detail seen in the picture. Some dust still may have been in the local atmosphere since details are somewhat subdued.—J. E. Peterson

(1°N, 147°W; MTVS 4174–57)

Most of the plains on Mars probably were formed when huge volumes of fluid lava erupted onto the surface and buried the pre-existing terrain. These volcanic plains were subsequently buried under a mantle of wind deposited sediments. The fluted and lobate escarpment in the center of the picture at right was probably the terminal end of an old lava flow that has been stripped of its cover of sand and dust and eroded by the action of the violent winds. This erosive process has also etched and enlarged fracture patterns on top of the flow.—E. C. Morris

(17°S, 136°W; MTVS 4179–30)

Subdued escarpments (below) may be seen along the margins of some plains. They may be the terminal fronts of ancient lava flows, partly mantled by eolian deposits. Similar lobate escarpments are seen on the lunar maria.—E. C. Morris



(51°N, 263°W; MTVS 4289–48)

In northern latitudes the plains are characterized by numerous small craters, hills and knobs, and patchy light and dark markings. The dark markings appear to create patterns, almost polygonal in form, similar to patterned terrain in the Earth's polar areas. —E. C. Morris

12
Polar Regions

The martian polar regions are of special interest because they contain two unusual and unique terrains, pitted plains and layered deposits. These two regional units are superposed on ancient densely cratered terrains in the south polar region and on relatively lightly cratered plains in the north. The uniqueness of the etch-pitted plains and layered terrains to the polar regions leads to the inference that their formation must involve frozen CO_2 or H_2O.

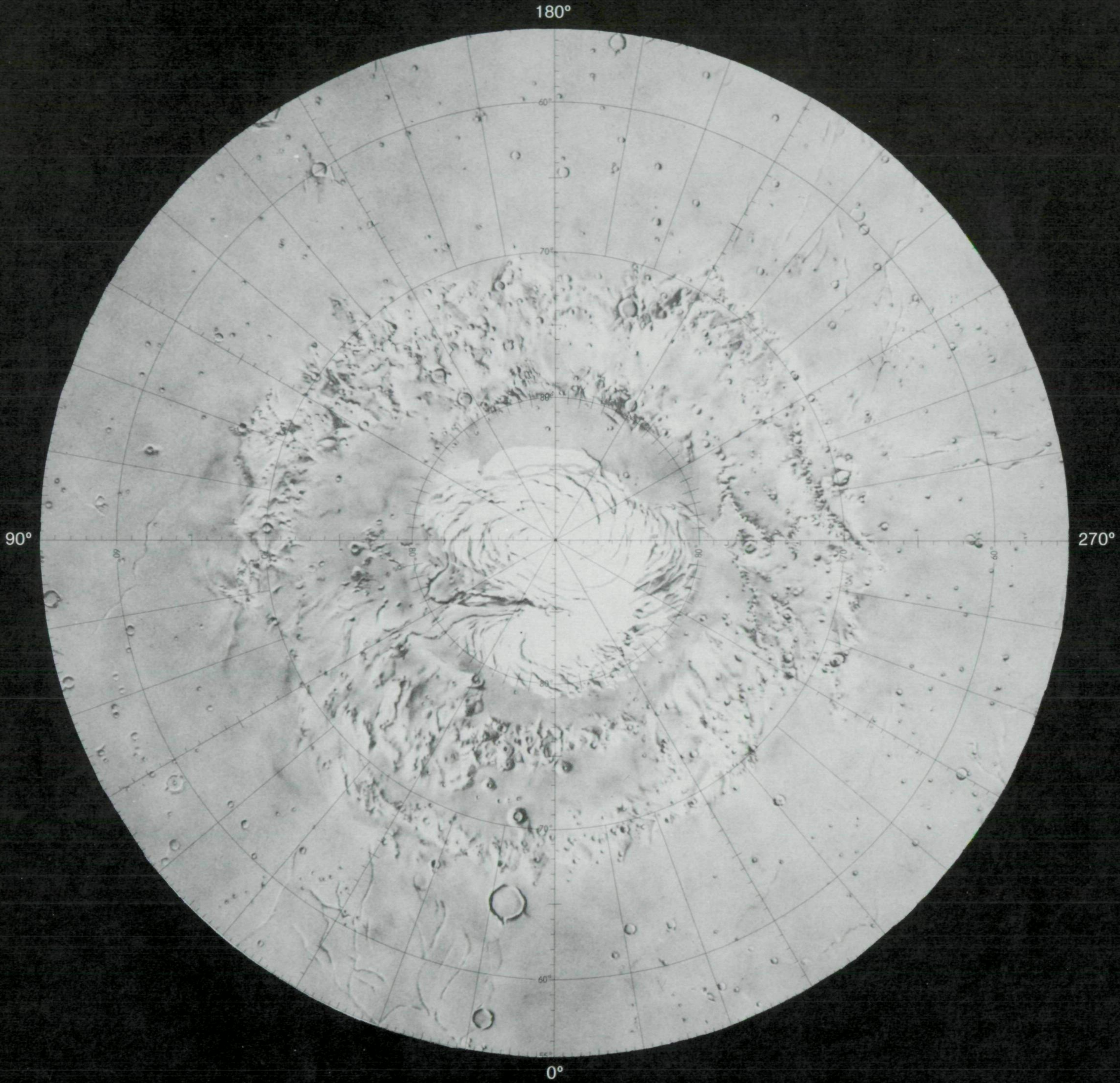
The pitted or etched plains vary widely in appearance, but typically are characterized by a level surface indented by numerous pits or irregular depressions. In places the pitted plains are being eroded, exposing the underlying cratered terrain. The processes of burial and exhumation do not appear to have modified the underlying terrain significantly.

The layered terrain is characterized by narrow, evenly spaced bands interpreted to be ledges of outcropping strata of nearly horizontal strata. The strata are from 20 m to 50 m high, and a sequence composed of more than 100 such units has been measured near the south polar region. The absence of craters in layered terrain suggests that either it is one of the youngest units on Mars or the most actively eroded.

The polar ice caps lie upon the laminated terrain. Each pole has a permanent cap composed of frozen carbon dioxide or water and a thin ephemeral layer of carbon dioxide, which forms poleward of the 60° parallels each winter and evaporates each summer.

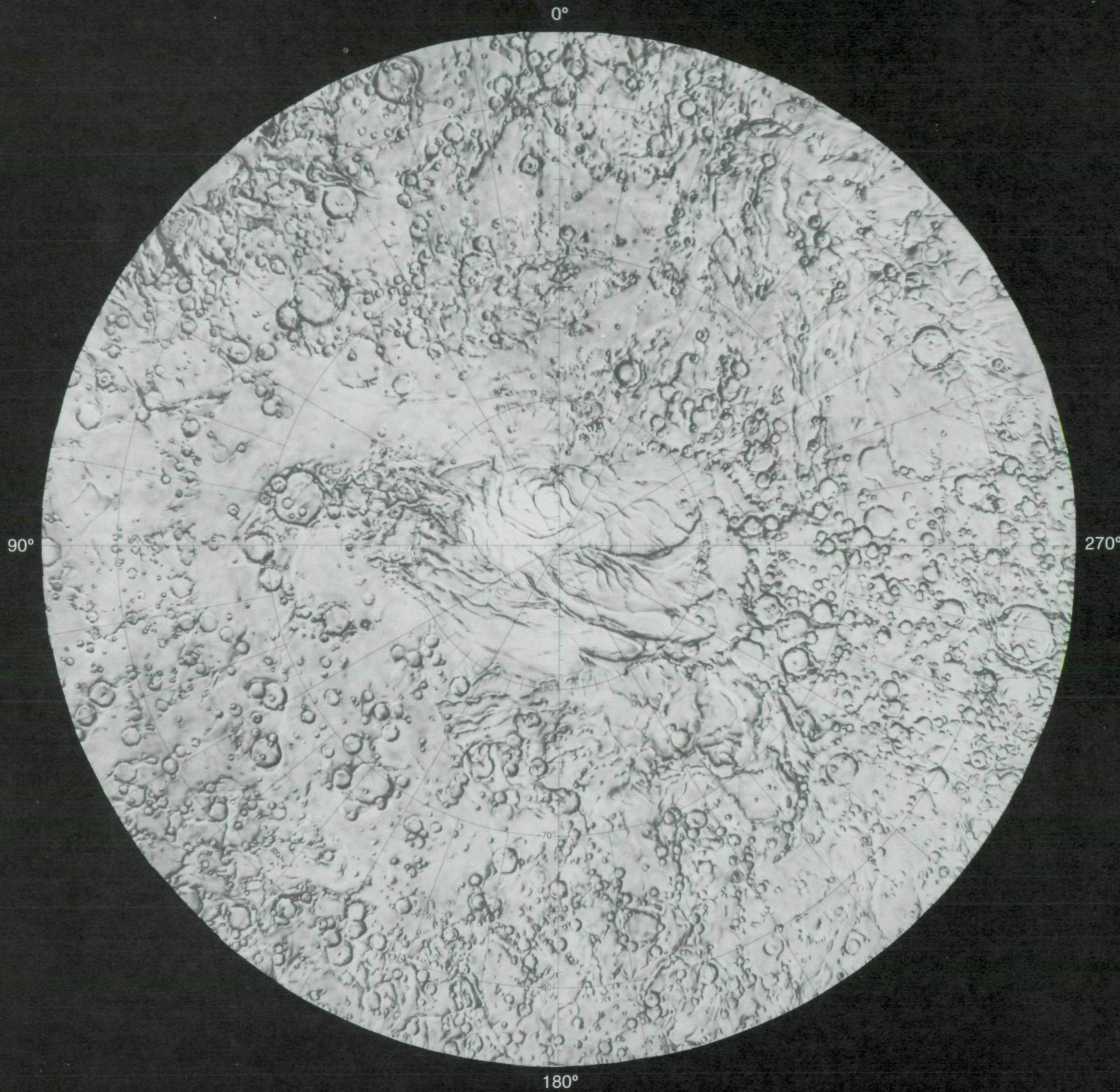
The cratered plains are obviously the oldest units in the polar regions because they are overlain by all of the other units. The pitted plains are believed to have been deposited next. Their origin is problematical, but the most convincing explanation seems to be that they represent a thick blanket of fine dust which has settled out of the atmosphere at the poles perhaps trapped by water and carbon dioxide ices. Locally this blanket has since been eroded by the wind, producing pits. Layered terrain, the youngest unit, occurs within about 15° of the poles. The obvious stratification within the laminated terrain may have been caused by periodic changes in atmospheric conditions while the material was being deposited.—L. A. Soderblom

NORTH POLAR REGION



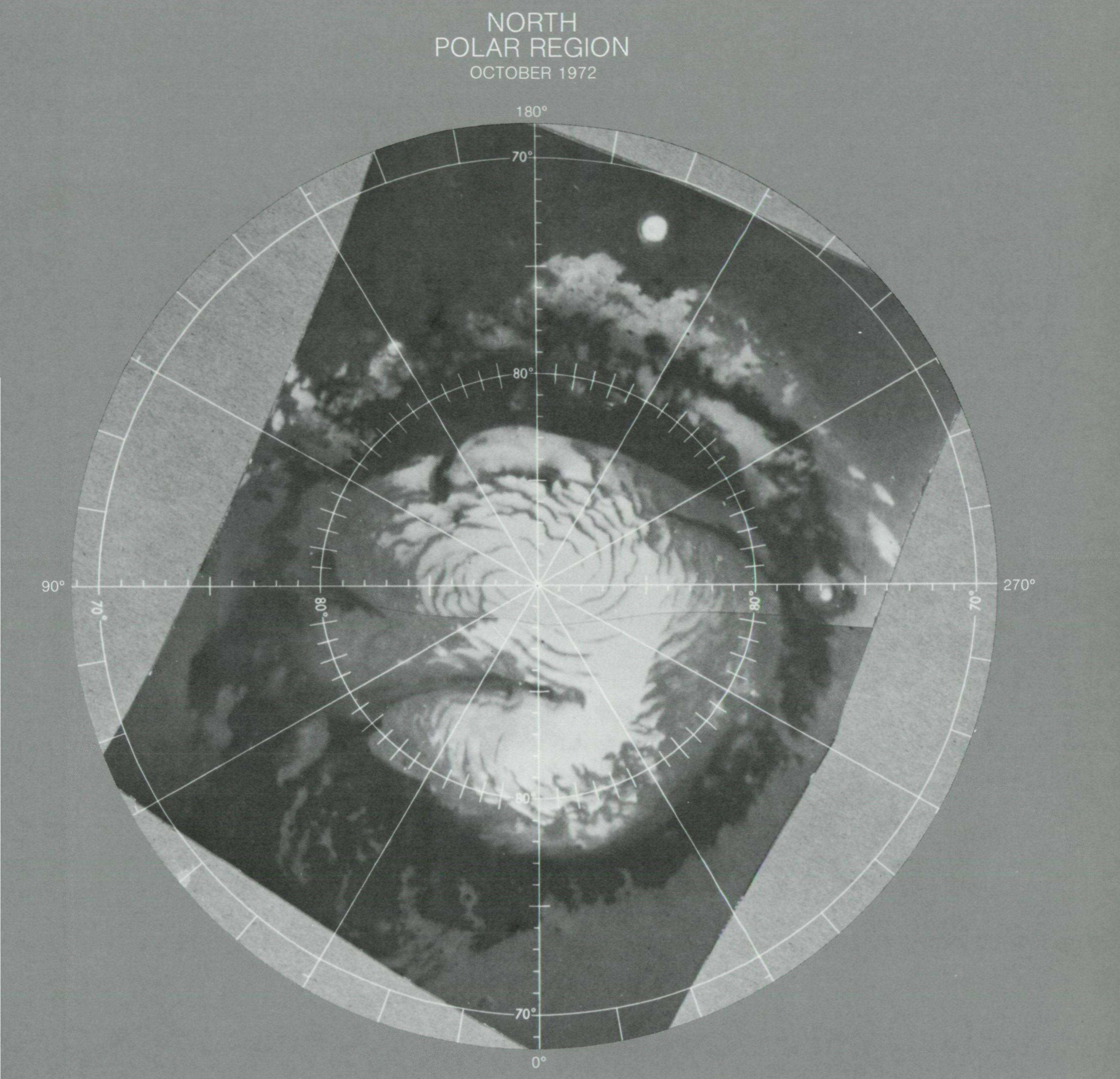
Airbrush renditions give a generalized overview of the north polar region and the south polar region. They clearly show the residual ice caps and the distributions of the various types of terrain. The south polar region seems much more heavily cratered than the northern one. This is probably because the north pole pictures have much

SOUTH
POLAR REGION



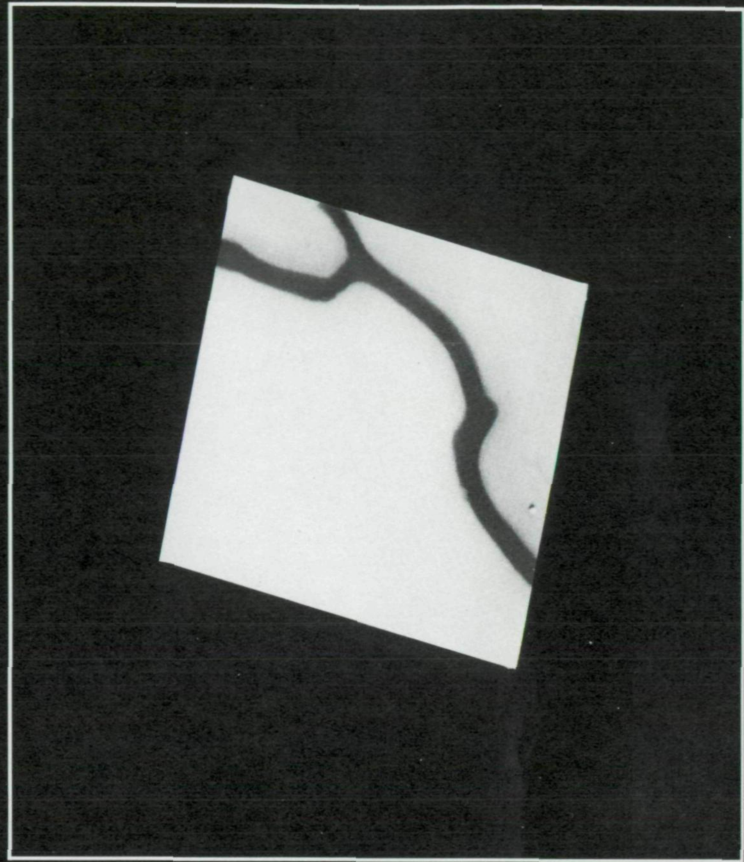
poorer resolution. Erosional debris blankets which mantle terrains surrounding both polar zones were probably derived through the continual erosion and transport of material from polar deposits to lower latitudes.—L. A. Soderblom and T. J. Kreidler

The frost in the north polar region is shown above covering a region about 2700 km wide about five or six martian weeks after the vernal equinox (August 1972) and at right when nearing its minimal extent approximately two weeks after the summer solstice (October 1972). The frost cover had a peculiar polygonal shape that became very pronounced during the last stages of recession of the cap. It is more likely to

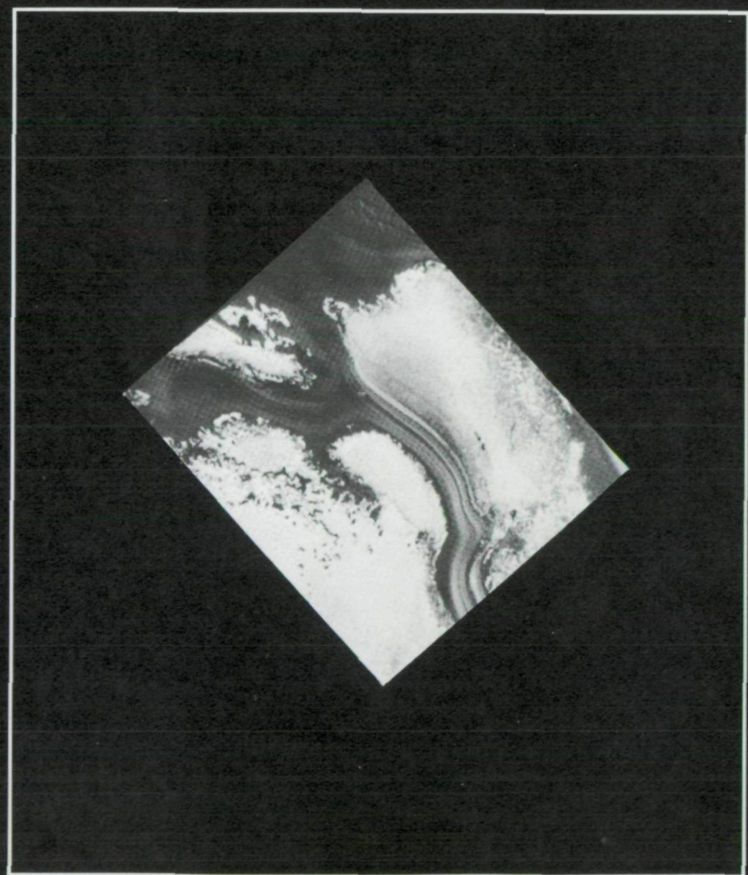


have resulted from regional phenomena than from local scarps or ridges. Regional textural alignments could have been induced by stable wind patterns. Note the crater at 73°N, 198°W in the mosaic at right. It trapped and shielded frost from the Sun, leaving a large patch on its floor.—L. A. Soderblom

REV 11



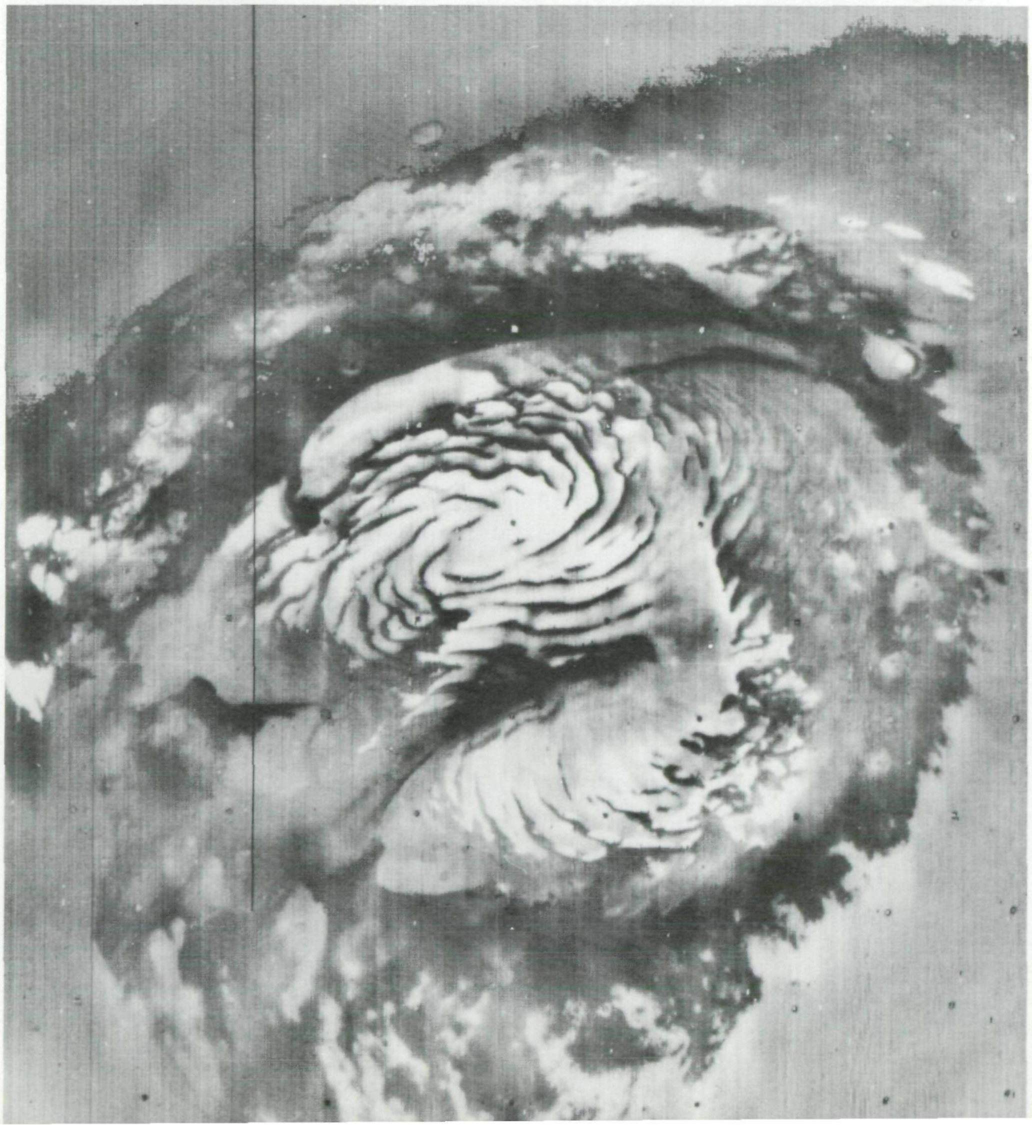
REV 231



(85°S, 355°W; IPL 1312/023810, 7352/184744)

From November until March the south polar cap was in the late stages of its retreat, shrinking to a residual cap about 6° in diameter. The conspicuous curvilinear markings seen as bright bands in 1969 by Mariner 7, defrosted early in 1971 to become the dark bands shown here. These high resolution photographs were taken 110 days apart by Mariner 9. In the initial stages of its retreat the windows in the cap continually changed, but by early 1971 they became fixed and unchanging. The dark features are bare ground, where ice has evaporated from sun-facing slopes. The permanent cap probably contains substantial water, if it is not all water, because a permanent mass of frozen CO_2 would collect water even from Mars' dry atmosphere. The width shown in each photograph is about 100 km.—L. A. Soderblom

(89°N, 200°W; MTVS 4297-47)
The martian north polar frost cap approached its minimal extent about one-half martian month after summer solstice on October 12, 1972. The cap is about 1000 km across. Its topography and the curved patterns in the interior of the frost cap are interpreted as a series of stacked, slightly concaved plates, the upper one of less areal extent, with edges that have been smoothed and modified. The individual plates may consist of from 20 to 40 separate layers, with an aggregate thickness of perhaps one kilometer. The outline of the residual cap and configuration of the interior markings arise from the frostfree Sun-facing slopes along which layers outcrop. A dark collar of rougher textured terrain surrounds the smoother polar-layered sedimentary complex localized in the central regions of both poles.—L. A. Soderblom



(82°S, 85°W; MTVS 4247–7)

Contact between layered terrain and pitted plains (above) is shown in this photograph of an oval mesa of laminated terrain nesting on underlying pitted plains. In several cases, craters can be seen emerging from beneath the layered deposits along their margins. One crater, showing only its rim, protrudes through the blanket of the pitted plains in the upper center of the picture. The jagged pits and hollows of a pitted plain area are dramatically displayed in the lower part of the view.—L. A. Soderblom

(71°S, 358°W; MTVS 4234–15)

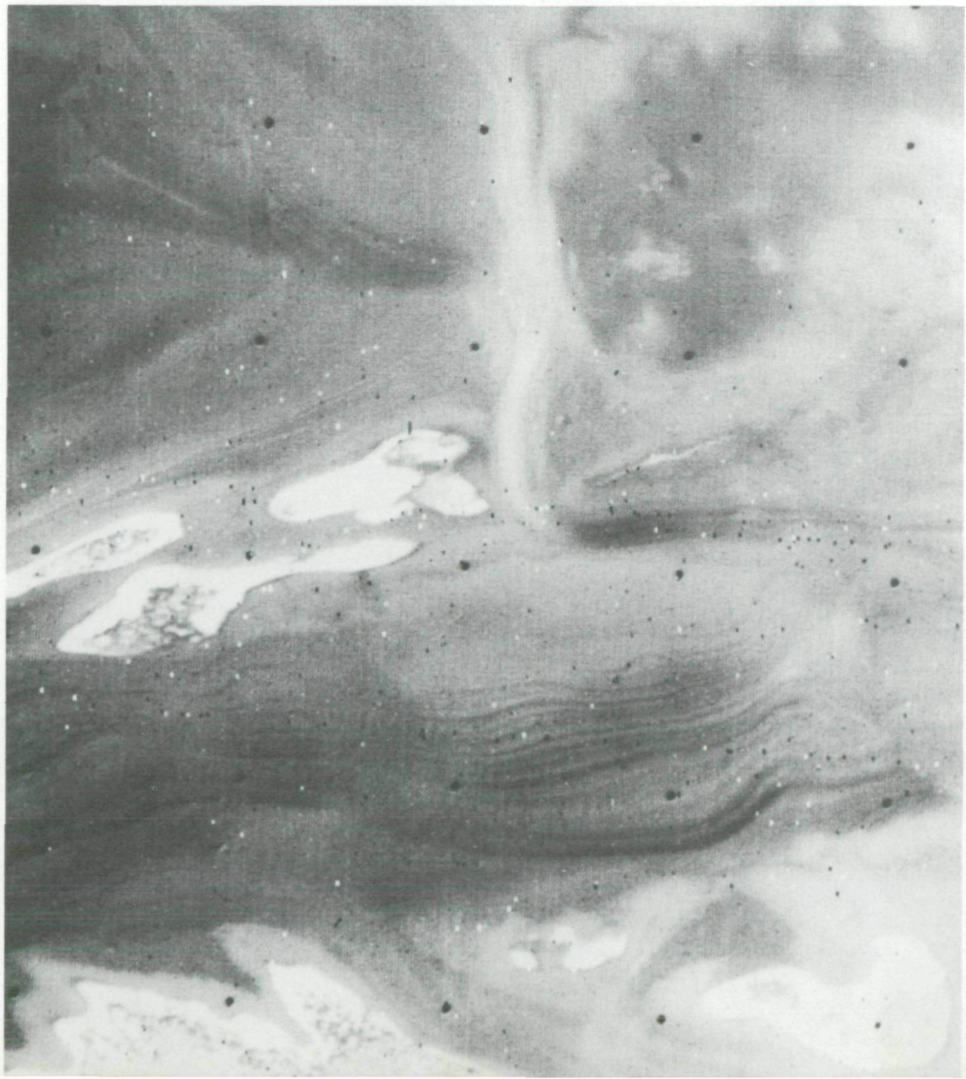
Integrated pits (right) are etched into a massive layer blanketing much of the south polar region. An underlying rough bedrock surface with partially exhumed craters is exposed in the pit floors. Slump blocks on pit walls and dark albedo markings at the bases of two or three sunlit walls are particularly unusual. Some pit walls are estimated to be 500 m high. The plain that is shown here is being eroded by wind action into irregularly shaped pits that resemble the markings left on a metallic surface after it has been etched with acid.—R. P. Sharp

(75°S, 229°W; MTVS 4213–21)

Polar layered terrain (left) is one of the most striking martian surface features. From the ground the layers may look like many of the mesas in the American Southwest. Individual layers are probably from 20 to 50 m thick. Their origin is a mystery. Smooth, gracefully sculptured surfaces with gentle slopes are characteristic of this terrain. The upper edges, unlike those of slopes in the pitted plains, are rounded. Layered terrain is essentially crater free, indicating that it is of relatively young origin or recent erosion. The seasonal frost cap is believed to play a part in the formation of layered terrain, perhaps trapping dust particles which settle as the ice is formed.—L. A. Soderblom

(83°S, 37°W; IPL 1403/203733)

This view of the polar cap edge shows outliers of ice resting on a mesa of layered terrain area about 80 km wide. Slopes of uniform width and declivity facing outward from the center of the residual cap defrost earlier than level areas because of their inclination.—L. A. Soderblom

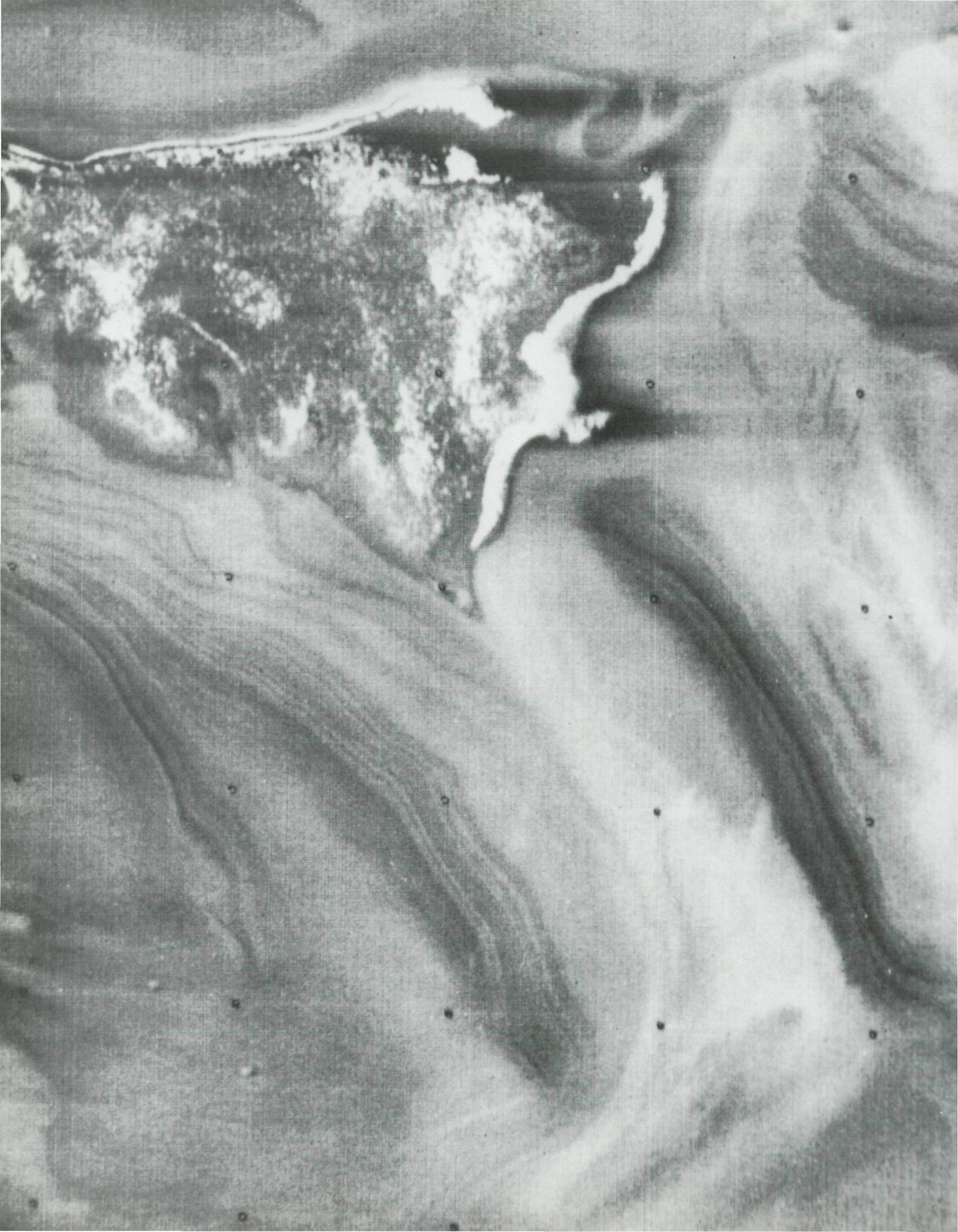


(80°S, 245°W; MTVS 4167–96)

These irregularly shaped features, located in the layered deposits of the martian south polar region, are probably products of wind erosion. The light colored splotch at far left is unusual in that it bears no relation to local topography. Also visible is a crater which was at one time buried by the layered deposits, but has now been exhumed by the wind. (Area shown is about 90 km wide.)—L. A. Soderblom and T. J. Kreidler

(86°S, 102°W; IPL 1444/131712)

Detail of the south polar cap (right). This picture was taken late in the mission when the cap had reached its limit of retreat. The underlying layered terrain is revealed on gentle slopes facing away from the pole.—L. A. Soderblom and T. J. Kreidler



(83°S, 53°W; MTVS 4261–19)

In this high resolution picture, part (70 km) of the residual south polar cap is seen resting on a mesa of layered terrain. The patchy appearance of the ice mass occurs because it consists of a myriad of disconnected remnants.—L. A. Soderblom and T. J. Kreidler

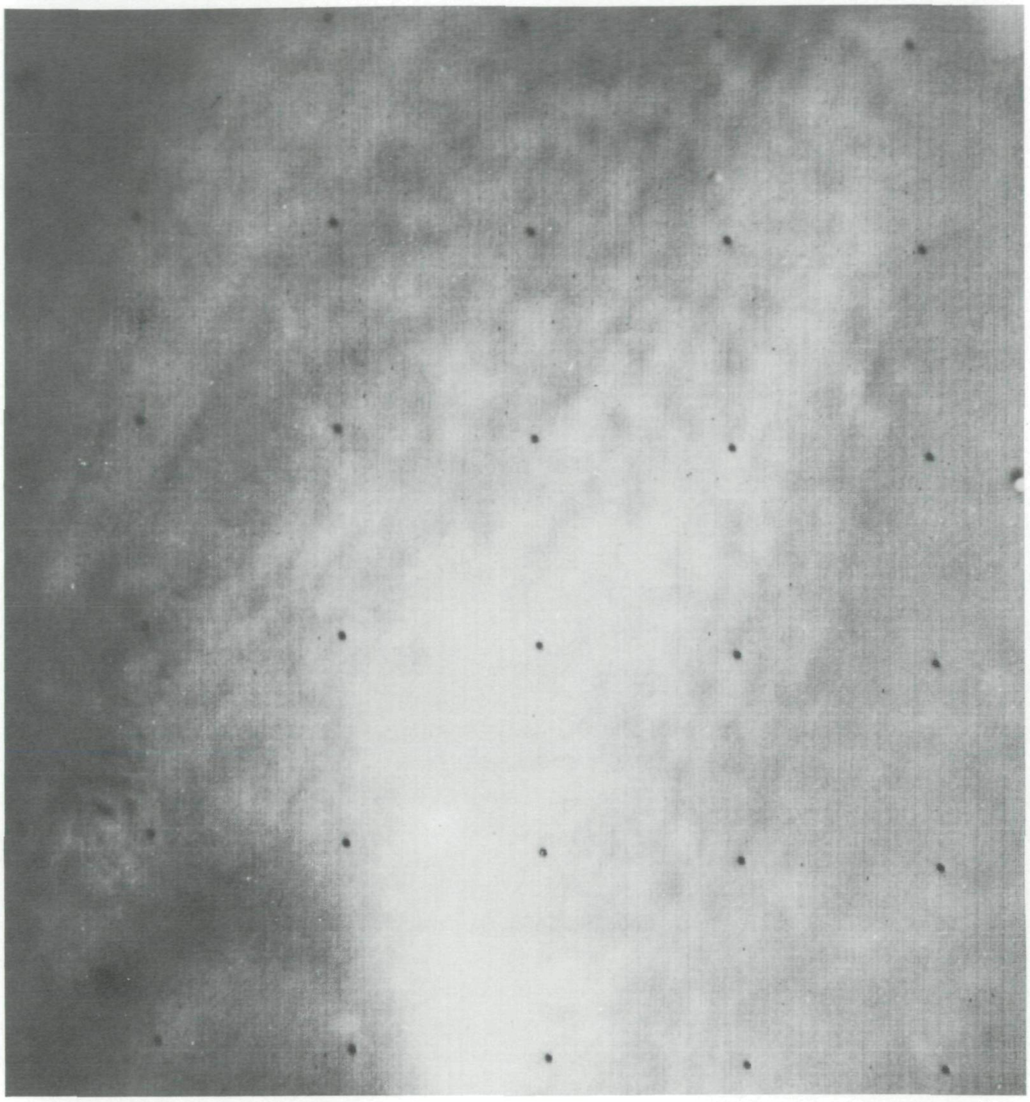
13
Clouds of Mars

The Mariner 9 view of another planetary atmosphere showed many features that are familiar in the Earth's atmosphere. Pressures and temperatures in the lower Mars atmosphere correspond to those at heights of 30 to 40 km above the Earth (about 1/200th atmosphere and $-70°C$). Condensation is a slow process under these conditions, but both CO_2, the predominant atmospheric gas, and water can freeze out and clouds do occasionally occur on Mars. The total amount of water in the atmosphere is very small; if condensed to liquid, a thin layer ranging from less than 0.01 mm to about 0.04 mm thick would form, depending on the season. Although the vapor concentration is extremely small in volume, compared with the Earth's lower atmosphere, the average relative humidity on Mars is actually fairly high. Thus, water-ice clouds do form whenever the atmosphere is intensely cooled by lifting or by emission of radiation. Extreme cooling, to temperatures in the neighborhood of $-127°C$, causes CO_2 clouds to form.

Cooling to very low temperature takes place in the polar regions during winter, and an extensive cloud cover forms a "polar hood." North of about 65° latitude, a general haze or fog of CO_2 ice crystals forms in the polar air close to the very cold ground. This cloud cover disappears in late winter to reveal a surface covered with CO_2 frost or snow. Between 45° and 55° latitude water-ice clouds form at heights ranging up to 20 km. Extensive systems of cloud waves form as the atmosphere flows over rough underlying terrain. The waves reveal that the wind direction is from the west at all heights at this season, and they indicate wind speeds ranging from as little as 10 m/s (about 23 mph) near the surface to more than 60 m/s at a height of 10 km. There is a transition zone between 55° and 65° in which large temperature variations occur, and the clouds in this region indicate large day-to-day weather changes, similar to those occurring in the stormy mid-latitude zones of the Earth.

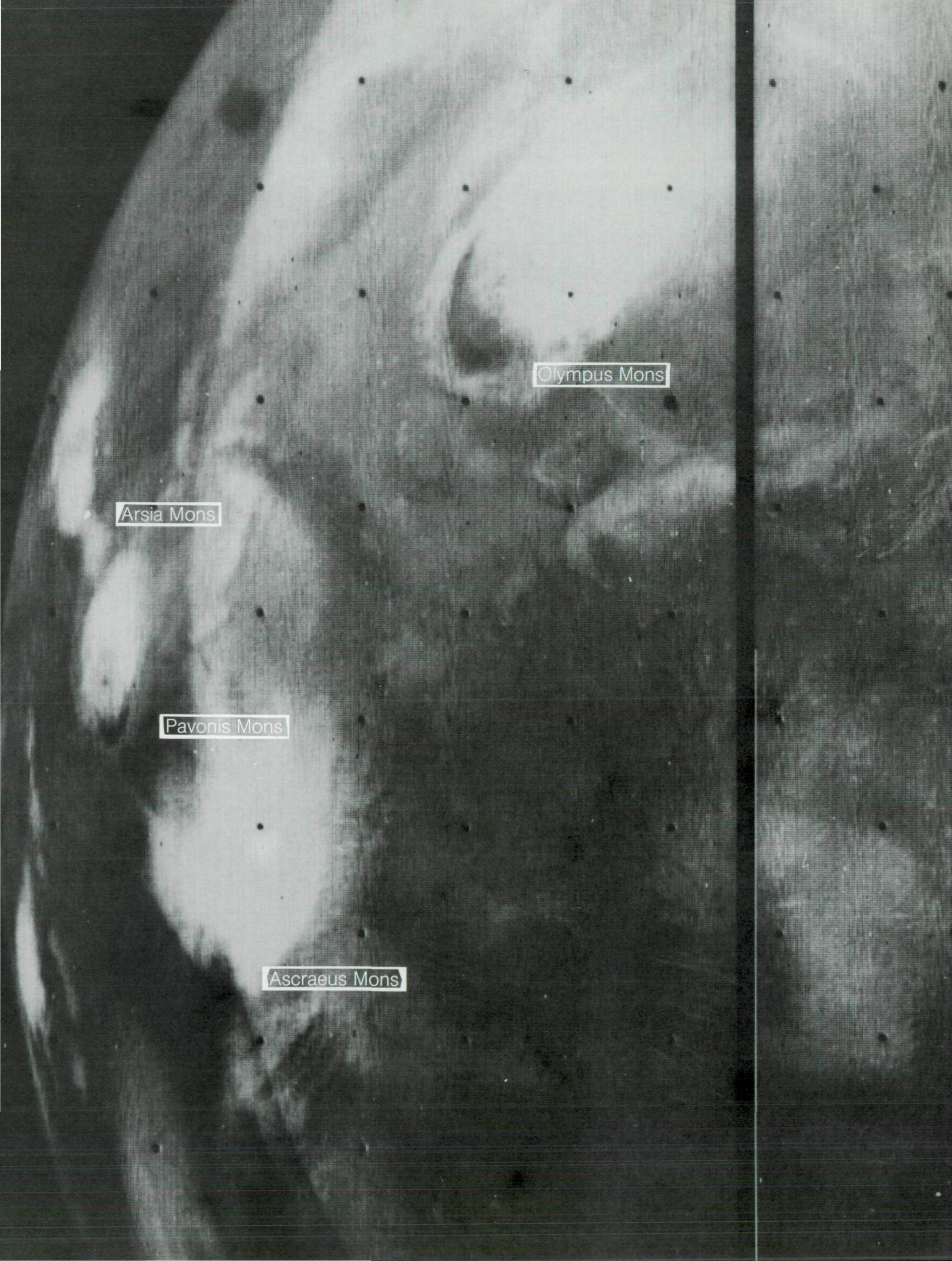
Recurrent afternoon brightenings occur in the Tharsis region during summer, and are due to water ice clouds which form as heated air rises up the outer slopes of the Tharsis Montes. These clouds occur during two seasons when the water content of the atmosphere is relatively high. Other condensation clouds have been observed over Argyre and Hellas, and over the north polar region in late spring.

Probably the dust storms are the most spectacular atmospheric events observed. These range in scale from the planetwide storm, which obscured the entire planet at Mariner arrival, to "small" storms covering areas of the order of 100 000 km^2 (about the area of Ohio). The latter were seen several times by Mariner 9 in the region of winter storms along the periphery of the north polar cloud hood, and they were also seen in the tropics. Because the dusty air is a strong absorber of sunlight these storms influence the circulation, and the planetwide storm showed a unique circulation regime driven by heating of the dust-laden air.—C. B. Leovy and G. A. Briggs

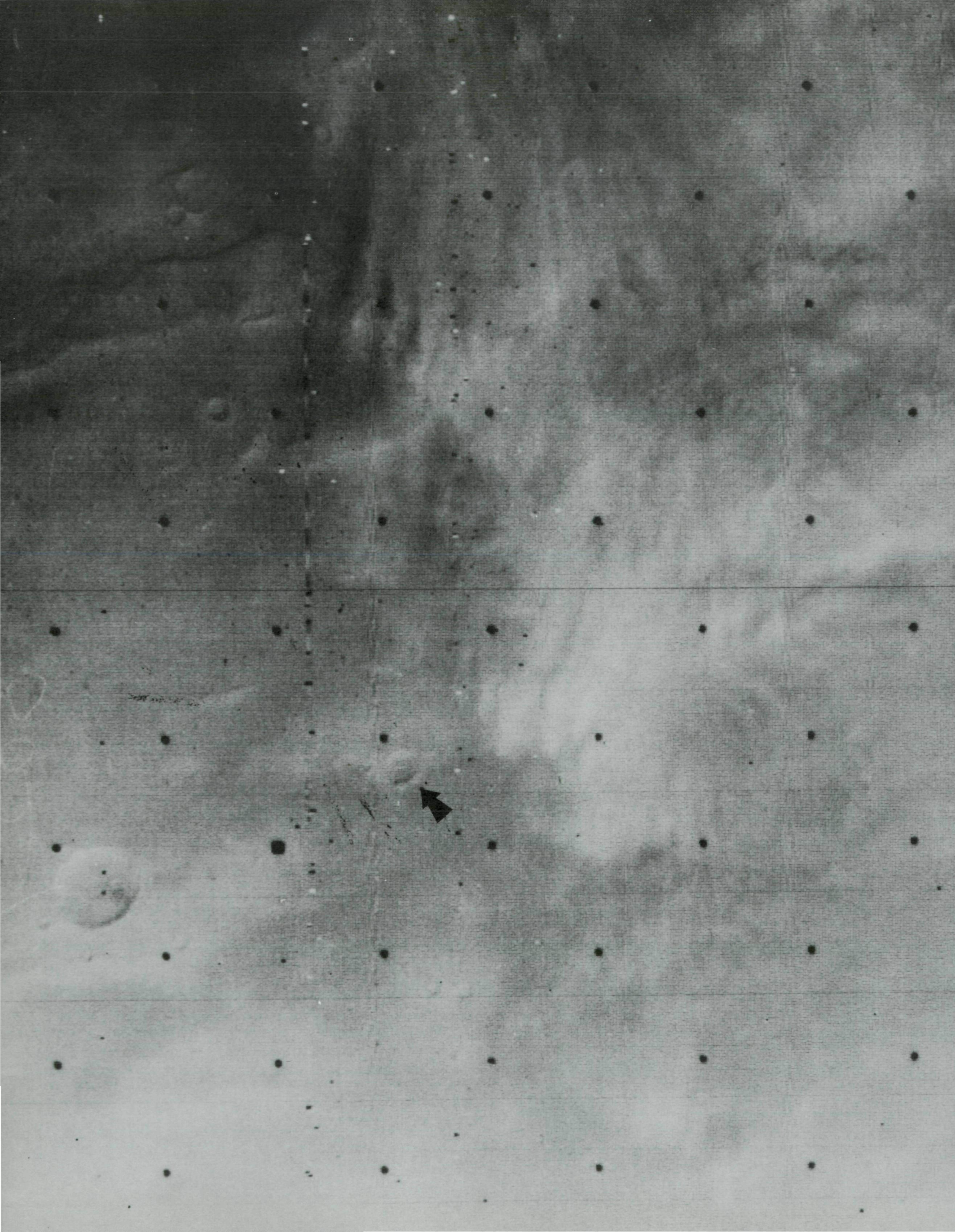


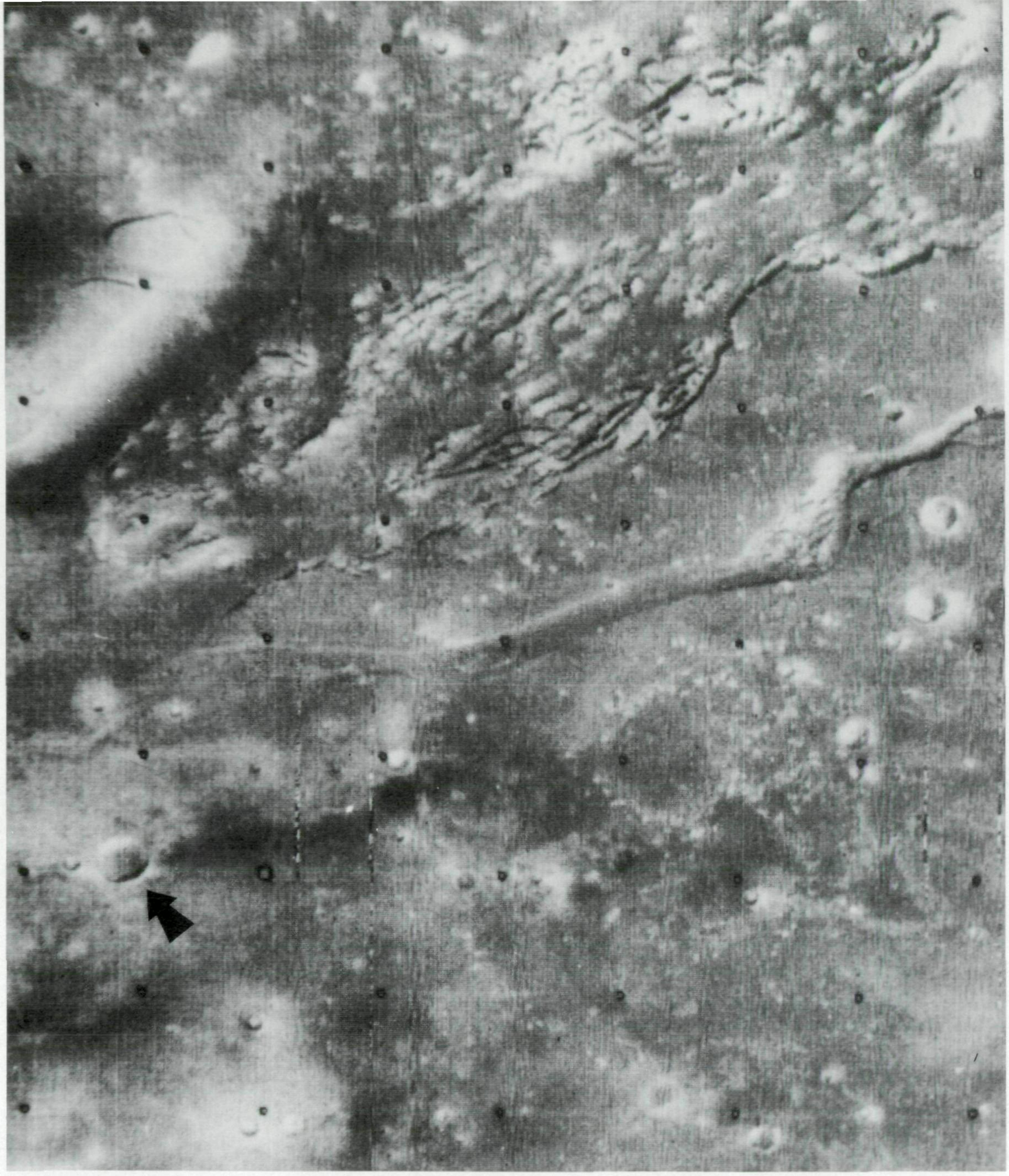
(19°N, 111°W; MTVS 4098–82)
(14°N, 110°W; MTVS 4098–78)

Some of the last photos received from Mariner 9 showed extensive cloud activity near the largest volcanoes on Mars (right). A high resolution picture (above) of Ascraeus Mons acquired at the same time showed cells suggesting convection, and the infrared spectrometer identified the clouds as water ice. They appeared to be relatively low, and were probably caused by air cooling as it moved up the slope of the volcano, but exchange of water vapor with the ground or even volcanic venting could also be involved.—B. A. Smith



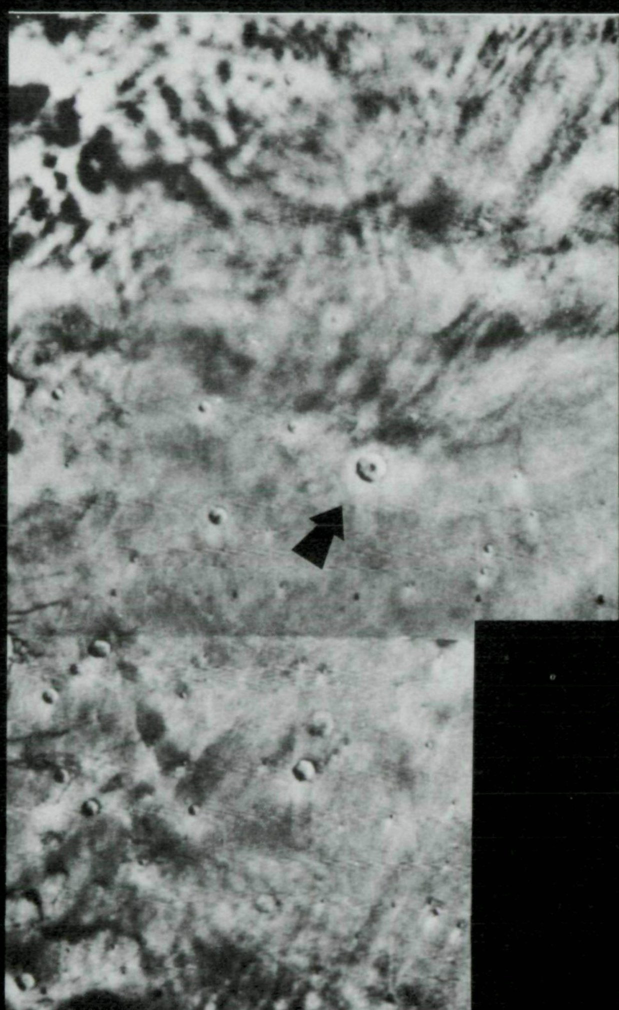
Olympus Mons
Arsia Mons
Pavonis Mons
Ascraeus Mons



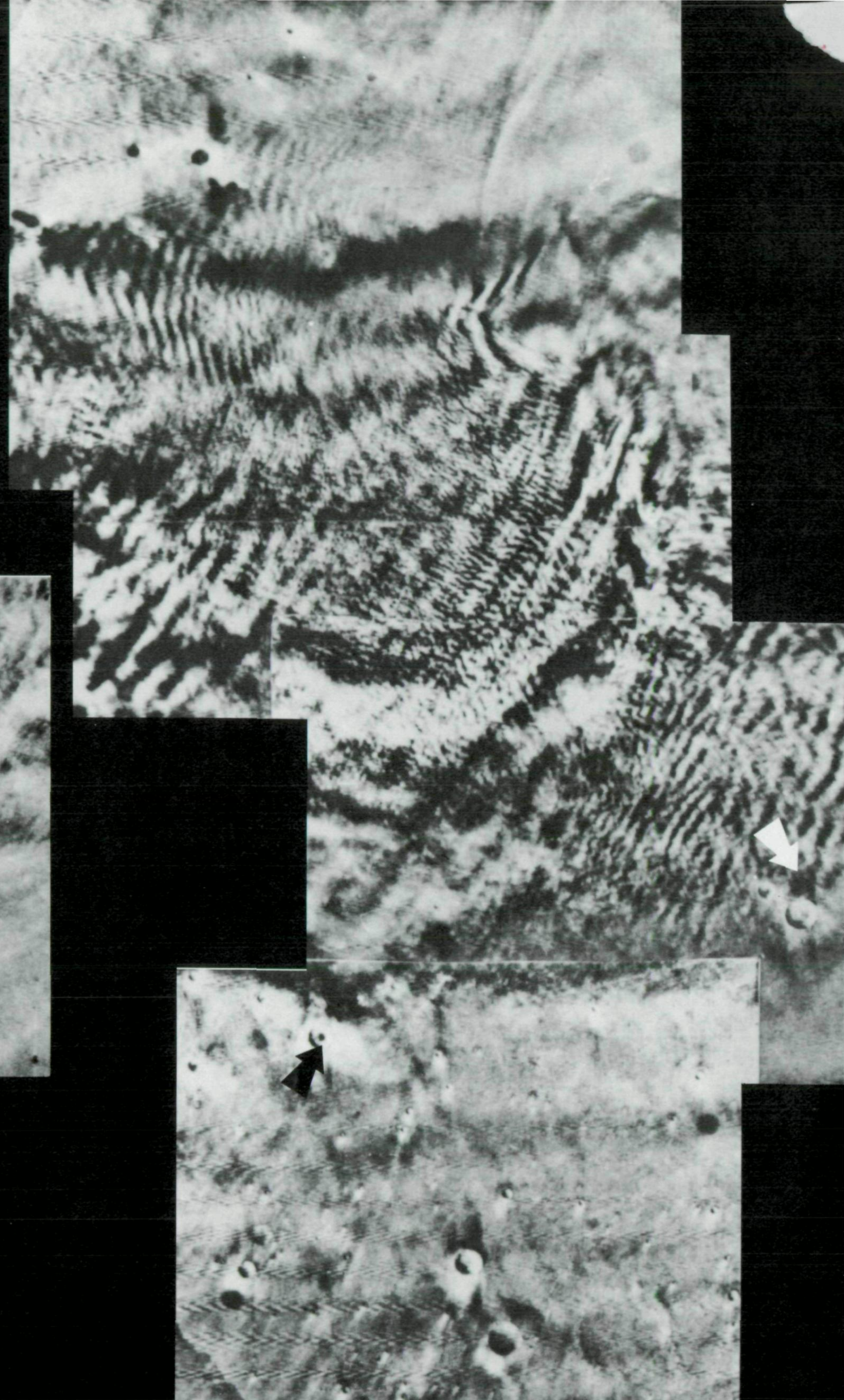


(15°N, 42°W; IPL 1765/105021)
(13°N, 42°W; IPL 1676/210508)

After the global dust storm subsided and the view of Mars from Mariner 9 was generally clear, local obscuration by streamers like those shown at left was observed. Twenty days later the streamers were gone (above); the arrows point to the same crater in both pictures. This region is about 650 km wide. Temperatures there were high and the streamers originated along terrain irregularities where turbulence could enhance the prevailing winds' ability to raise dust. Short-lived, localized dust storms of this type are familiar to astronomers as "yellow clouds" and are very different from the white clouds produced by condensation.—C. B. Leovy



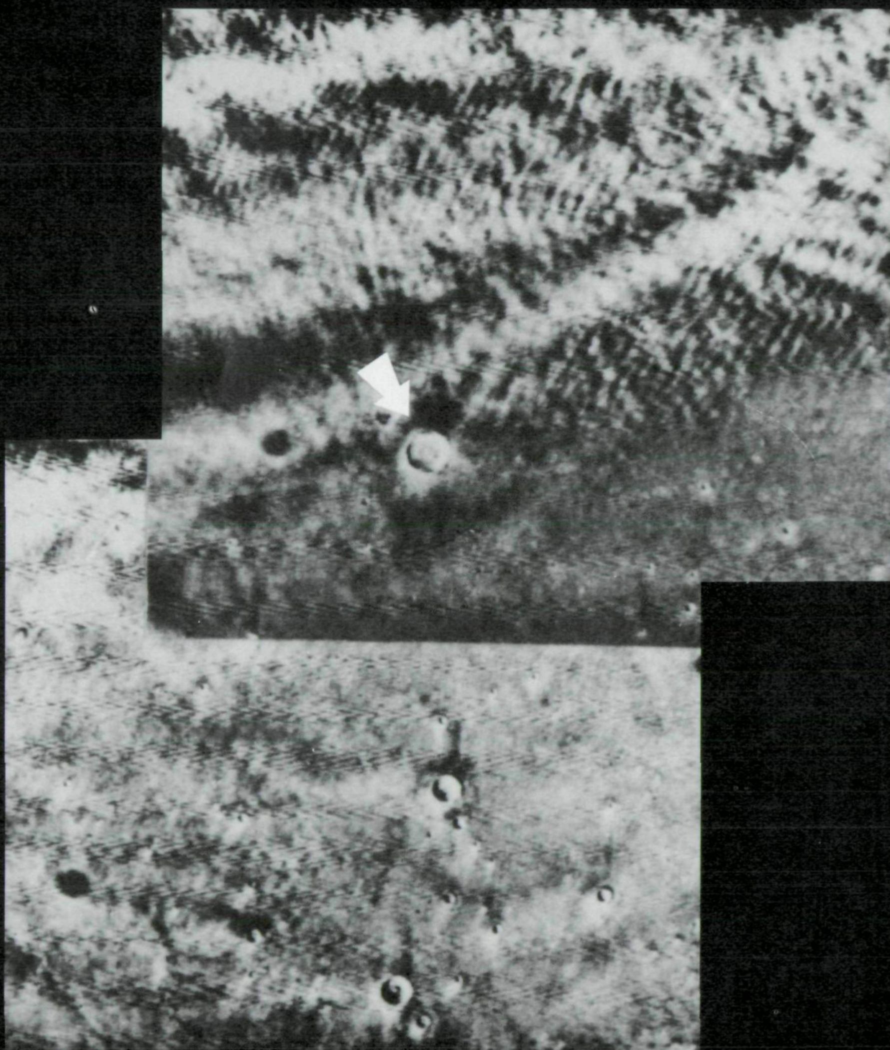
1



2

(48°N, 40°W)

Clouds appearing on three successive days along the southern edge of the north polar hood reveal a prevailing large-scale wind pattern (repeated craters indicated by corresponding arrows). Intensely cold air covers the northern part of the region shown. Some of the wave clouds on the second day of this sequence were aligned in parallel bands, southwest to northeast, and individual elements were perpendicular to the band. This structure suggests waves produced in shearing flow along the bands and perpendicular to the small wavelets. This type of structure is familiar in terrestrial satellite photographs of cold fronts and their associated jet streams. On the third day, the band system had moved 1000 km to the southeast. This movement is typical for terrestrial cold fronts, and martian cold fronts appear to behave similarly.—C. B. Leovy



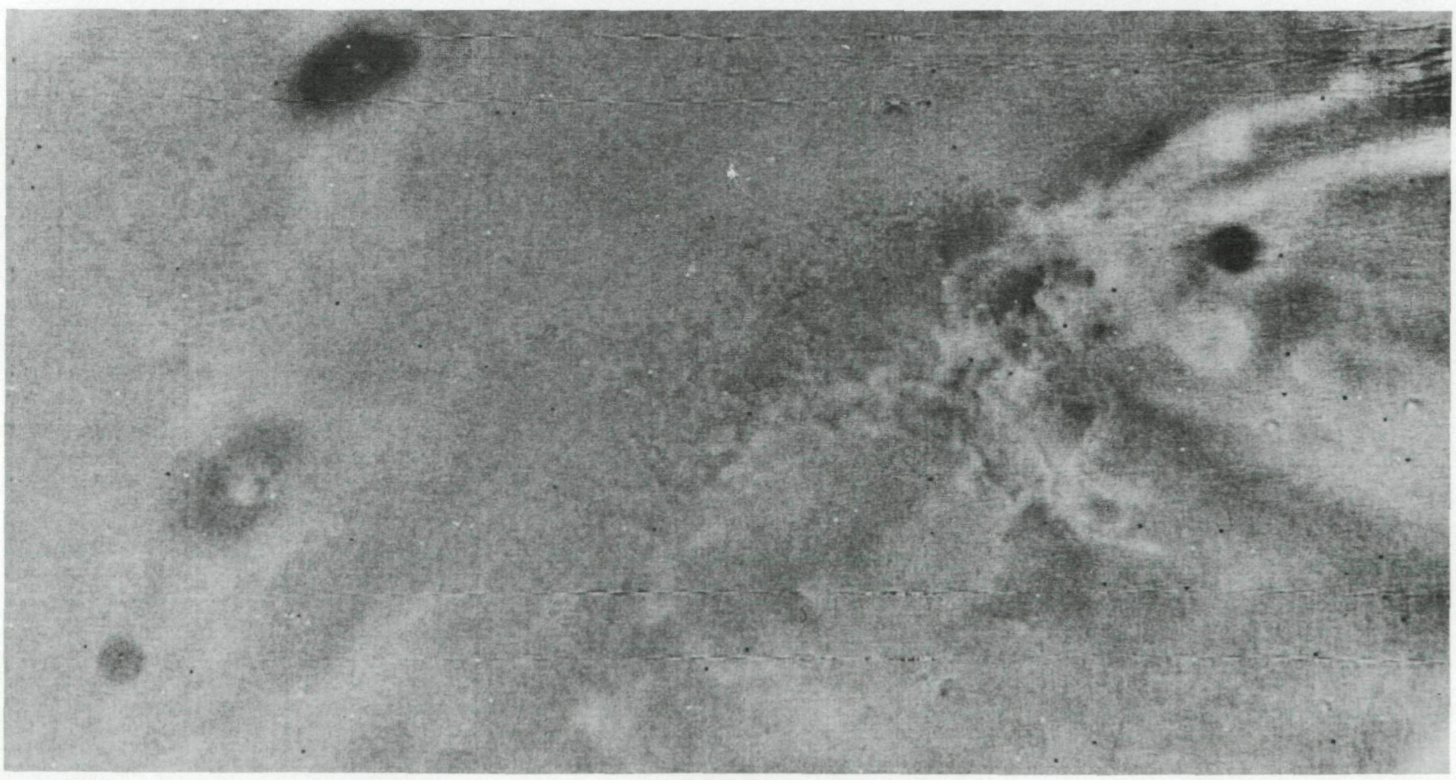
3

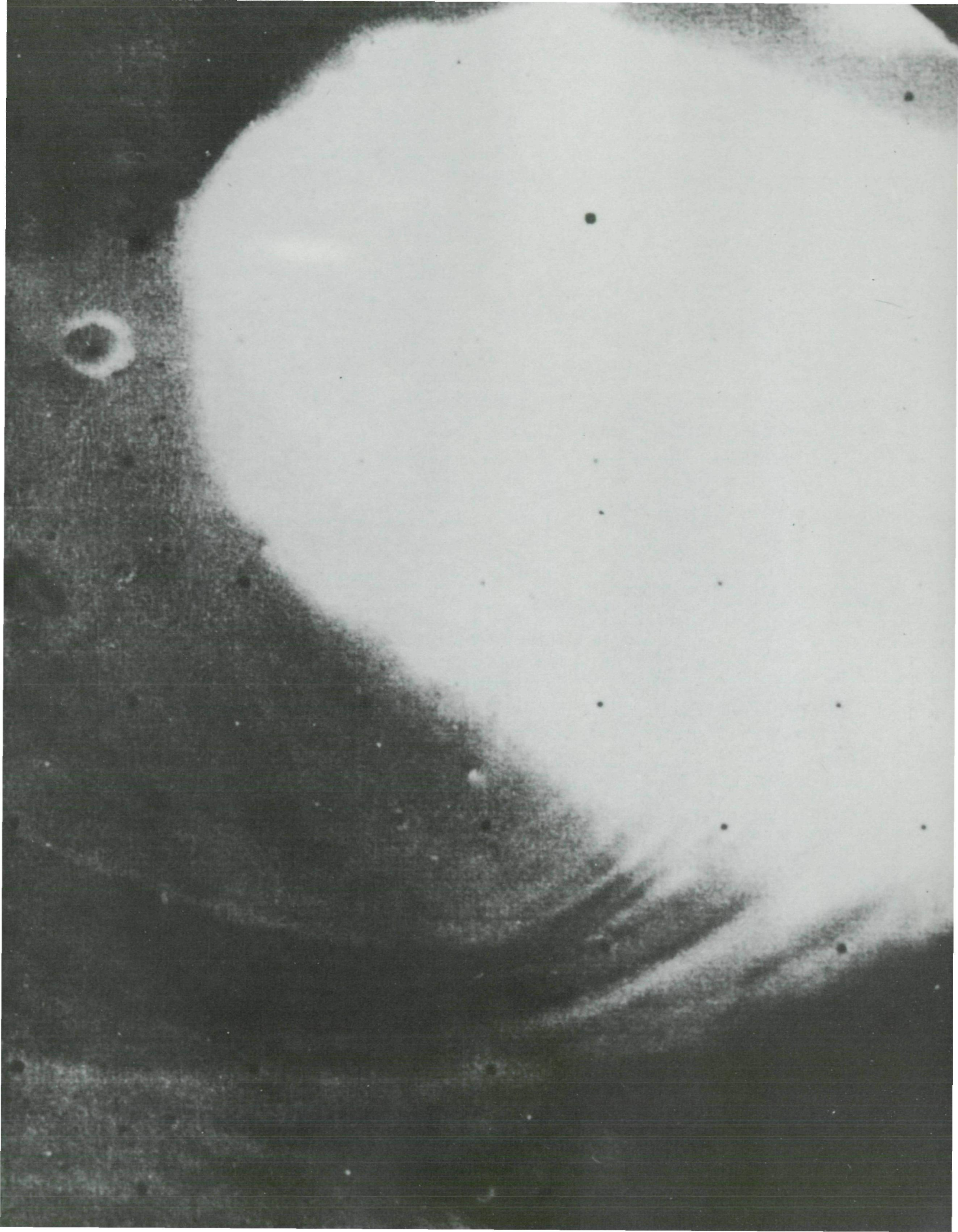
(71°N, 351°W; IPL 7283/213013)

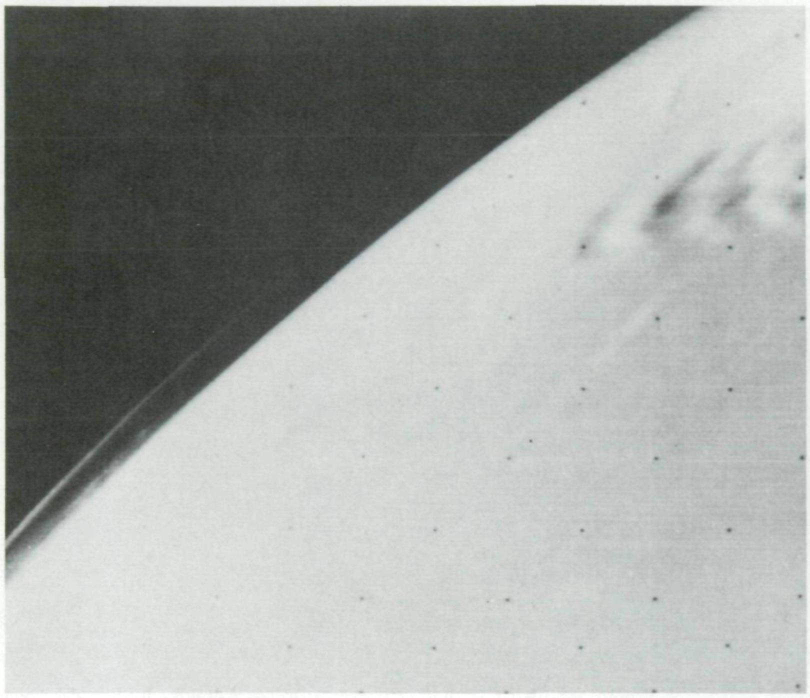
Mariner 9 sent back some pictures in the northern spring when the polar hood had cleared and the atmosphere there was generally very clear. Later photographs (one shown at right) showed that the atmosphere was again partially obscured north of about 45° latitude. Well defined cloud streaks extended south and west from the edge of the surface condensate cap. The streakiness may have been produced by strong winds blowing off the edge of the subliming polar cap, but this phenomenon is still poorly understood.—C. B. Leovy

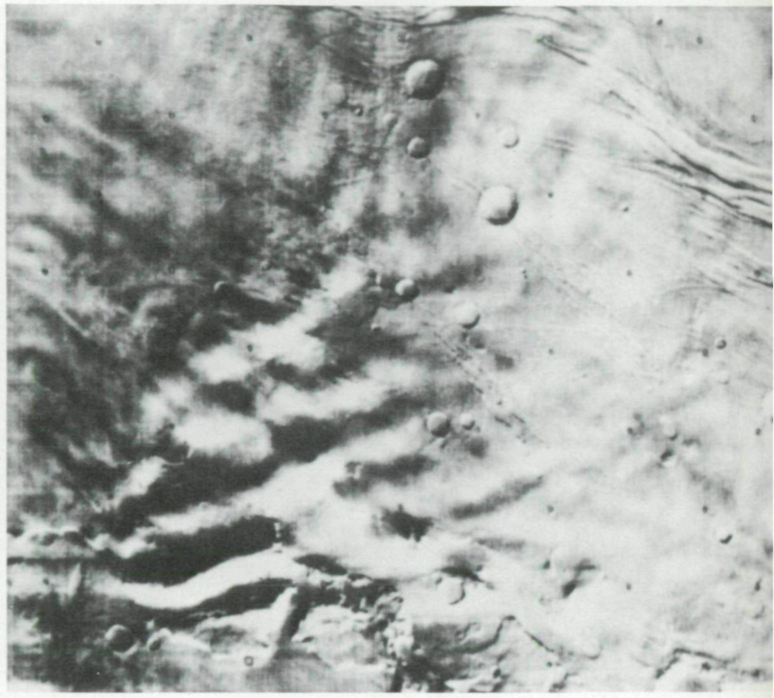
(8°S, 95°W; IPL 0083/151448)

The equatorial region around Tharsis Montes shows a general dust pall in this early photo. The peaks of towering volcanoes appear as dark rings at the left, and at right the bright outline of a vast canyon complex, later identified as the west end of Valles Marineris, can be seen. Observations showed that the canyons are several kilometers deep and the brightening here is attributed to the depth of the dust scattering back the Sun's light to Mariner 9's cameras.—G. A. Briggs









(45°N, 85°W)
(55°N, 73°W; MTVS 4154–93)
(43°N, 82°W; MTVS 4229–66)

The Mariner 7 photo at far left shows a white cloud in the Tempe region (arrow) that astronomers have noted there for many decades. Mariner 9 returned better views in 1972 showing parallel corridors of clouds that ranged up to about 30 km in altitude (above, left). When viewed vertically later, it was found that a surface ridge about 400 km long (above, right), oriented roughly north-south, caused the cloud waves. Their composition is probably dependent on the wind velocity. Strong winds produce oscillations that permit CO_2 to condense at high altitudes and water vapor at low, warmer elevations. Weak winds permit only the lower level condensation of water vapor into ice crystals.—G. A. Briggs

(63°N, 347°W; MTVS 4210–78)

This high resolution photograph shows details of the formation of a wave cloud over a crater in the north polar region. The wind is blowing from upper right to lower left, and a second wave cloud is forming about 40 km downstream. Both wave clouds appear to be quite turbulent. The generally diffuse appearance of the scene is caused by partial obscuration by a widespread thin haze of condensed CO_2 or H_2O. The large crater stands out prominently because of surface ice or snow (CO_2 or H_2O) around its rim.—G. A. Briggs

14
Natural Satellites

The tiny martian moons Phobos and Deimos (from the Greek for "Fear and Dread") are very difficult to see with terrestrial telescopes. They were discovered only in 1877 by the American astronomer Asaph Hall, and were seen as faint points of light orbiting close to their planet. Virtually nothing was known about them until Mariner 9 returned the images shown here. Because their orbital characteristics were not known with sufficient precision, the first photographs were taken at substantial distances. These images were then used for accurate orbital determinations, which permitted accurate camera aiming for closeup photography.

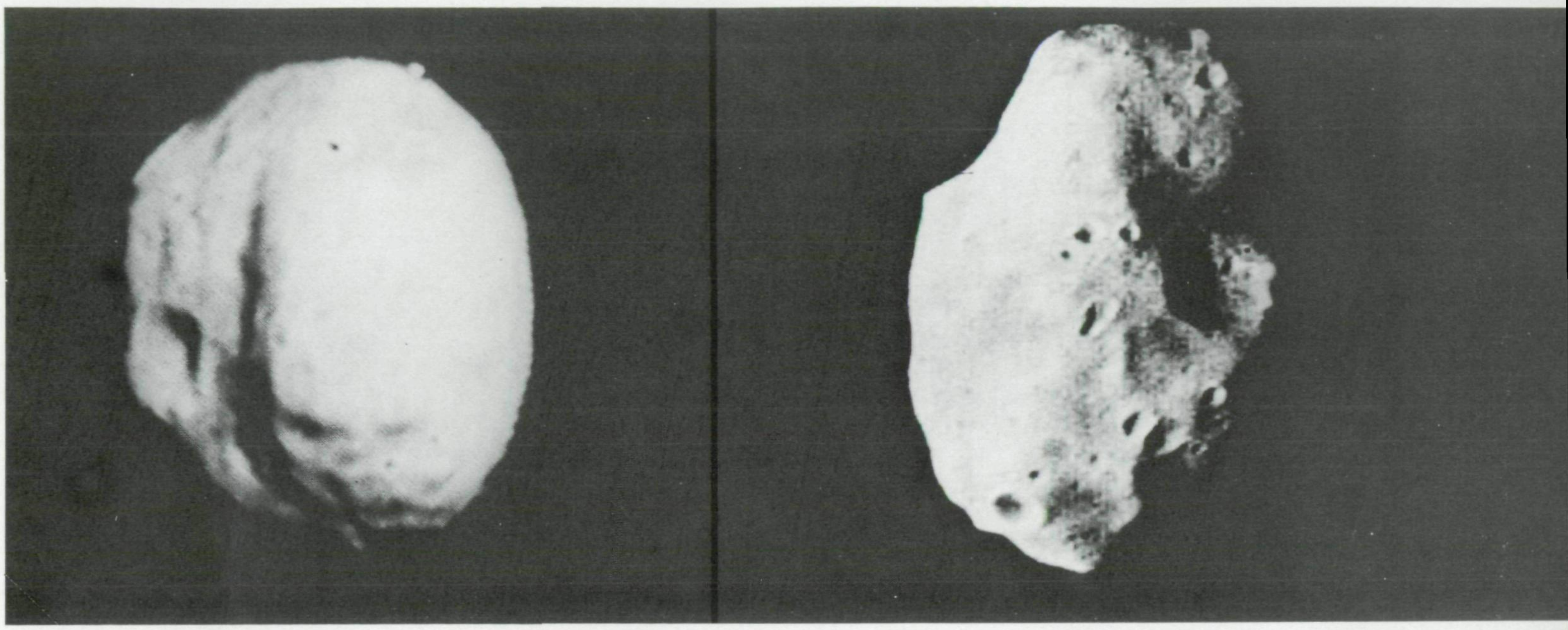
Phobos, the inner and larger of the martian moonlets, orbits at an average distance of 6100 km (3750 miles) above the surface of Mars. It proves to be an oblong mass about 20 by 25 km in its major dimensions (12 by 14 miles). Deimos orbits roughly 20 000 km (12 000 miles) above Mars, and is 10 by 16 km (6 by 10 miles) in size. Because the martian moons are so small, their gravity fields are too weak to force them into spherical shape. As with our Moon, each keeps the same side turned toward the planet.

Both Phobos and Deimos are heavily cratered by the impact of meteoroids. The number of craters appears to be close to the saturation limit, which occurs when so many exist on a surface that any new craters formed destroy an equal number of older ones. Rough estimates of the ages of satellites can be made by comparing their crater densities with those of similar areas on the Earth's Moon that have been positively dated by the ages of rocks returned by Apollo astronauts. Phobos and Deimos are believed to be at least 2 billion years old, and may date back to the early history of the solar system about 4.5 billion years ago. The satellites also serve as a useful standard of comparison for the crater densities on Mars. This comparison suggests extensive erosion of craters 1 km in diameter and smaller.

Both Phobos and Deimos are dark objects; most asteroids and meteorites are brighter. The few objects that are as dark contain large amounts of carbon or iron.

Studies of variation in brightness of these satellites suggest that they may be covered with a layer of fine particles. In the case of the Earth's Moon, such a regolith results from the shattering of rocks by repeated meteoroid impact. The gravity fields of Phobos and Deimos are so slight that fragments of impact-shattered rock would be thrown out into space. But these ejecta would be captured by the gravity field of Mars, going into orbit about Mars where the weak gravity of each satellite could sweep it up again.

Theoretical studies of the small satellites indicate that they need rocklike strength to escape total disintegration from meteoroid impact. Since their weak gravity appears insufficient to have originally formed them into cohesive materials of sufficient strength, it seems likely that they were once part of a much larger solid rock, and were fragmented by the impact of a large meteoroid.—J. B. Pollack

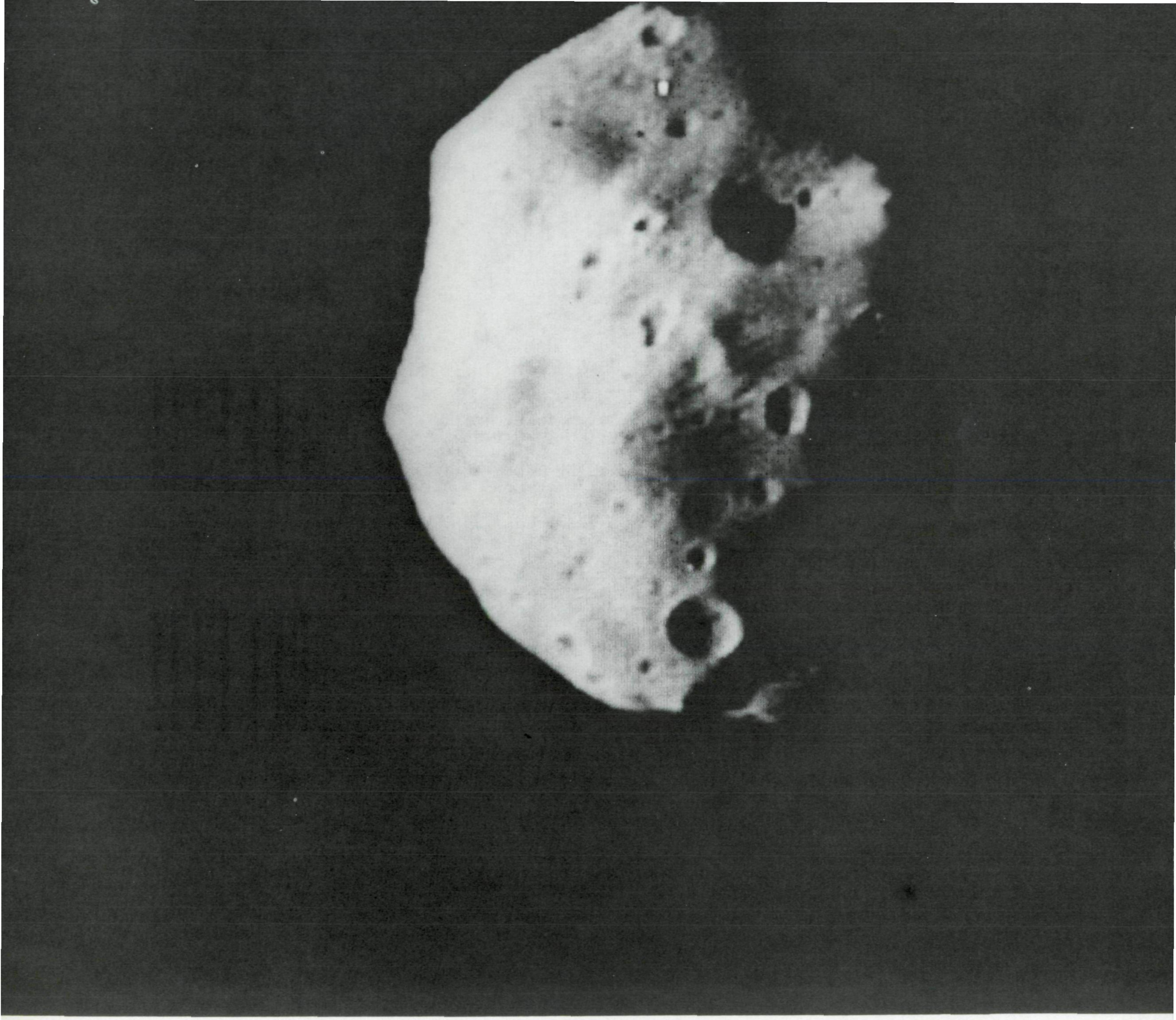


(IPL 1579/163600)

Phobos from afar at a range of 12 500 km (left) reveals only its largest craters. The diameter of the prominent crater near the terminator is about 5 km. The long linear edge that runs the length of Phobos is probably the result of fragmentation.—J. Veverka

(IPL 83/235451)

The best view yet seen by man of Phobos is this computer-enhanced picture taken at a range of 5540 km (right). The large crater at middle right, near the terminator, appears to have at least one small crater on its rim. More than a dozen other small craters are visible. The irregular edges of Phobos strongly suggest fragmentation. —J. B. Pollack



(MTVS 4109–9)

The profusion of craters on Phobos is suggested in this picture, which is also a minimum-range view (5760 km). Craters as small as 300 m in diameter are visible.—J. Veverka

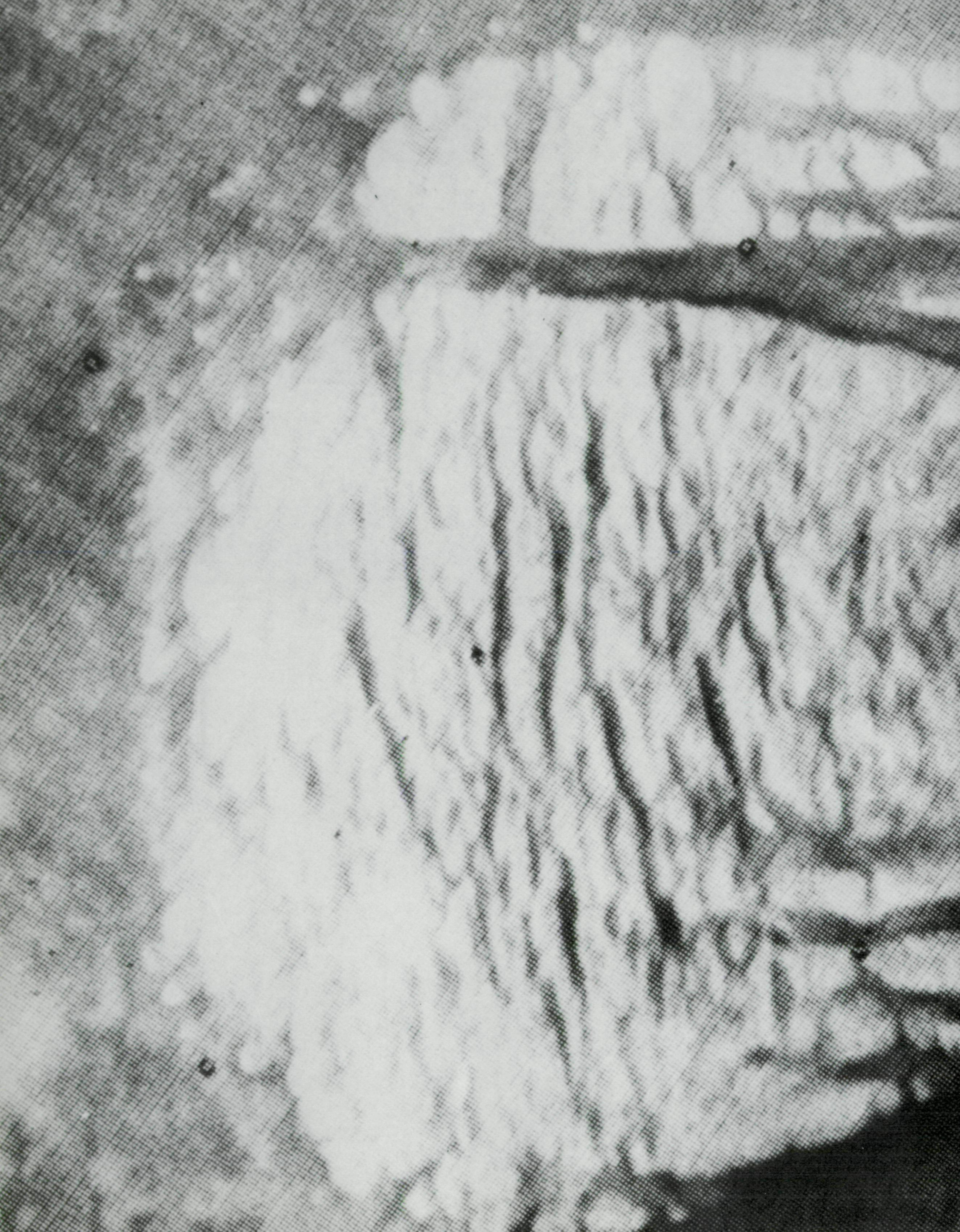
(IPL 1599/200513)

Deimos, photographed at a range of 5465 km, reveals less detail, although craters of all stages of freshness are seen. The old crater in the center is about 2 km across. —J. Veverka

15
Martian Enigmas

Many of the martian features seen in Mariner 9 pictures can be categorized because of their obvious similarity to features well known and long studied on the Earth and the Moon. Others, however, are puzzling. We cannot yet be sure whether their characteristics are unique to Mars, or whether it is just that the limitations on our current understanding of the red planet prevent us from confidently interpreting what we see.

More detailed study will doubtless lead to a better understanding. Some features may be clarified if we can find natural features on Earth that are analogous, and others may be explained if they can be simulated or modeled in a laboratory. Thus the present enigmas may lead us to a better understanding of the processes that operate on the cold, dry surface of Mars with its very thin atmosphere and periodic high winds. In the meantime, a modest and by no means exhaustive collection of these puzzling features is presented here as a sampling of the challenges that have been presented by Mars.—J. E. Peterson



(8°S, 335°W; MTVS 4216–54)

A strange white deposit occurs on the floor of a crater not far from the martian equator. Its high reflectivity suggests ground ice but its location makes this highly improbable. The deep tapering reentrants and the suggestion of considerable relief above the crater floor leads to the inference that it most probably is not a transient feature but rather a permanent deposit now in the process of being eroded by the wind. The origin of the deposit itself, which is about 18 km wide, remains an enigma. —J. F. McCauley

(74°S, 166°W; MTVS 4269–19)

An intricate crater (above) in the south polar region displays an arcuate slump mass inside the major crater wall. Both the rim and the slump mass are subdued by a mantling blanket. On the crater floor an arcuate scarp appears, which is 35 to 40 km in diameter and comparable in shape to the big crater. Branching ridges and furrows within may be due to erosion of a volcanic construct; dark pattern within may be volcanic ash.—D. B. Potter

(80°S, 245°W; IPL 326/171411)

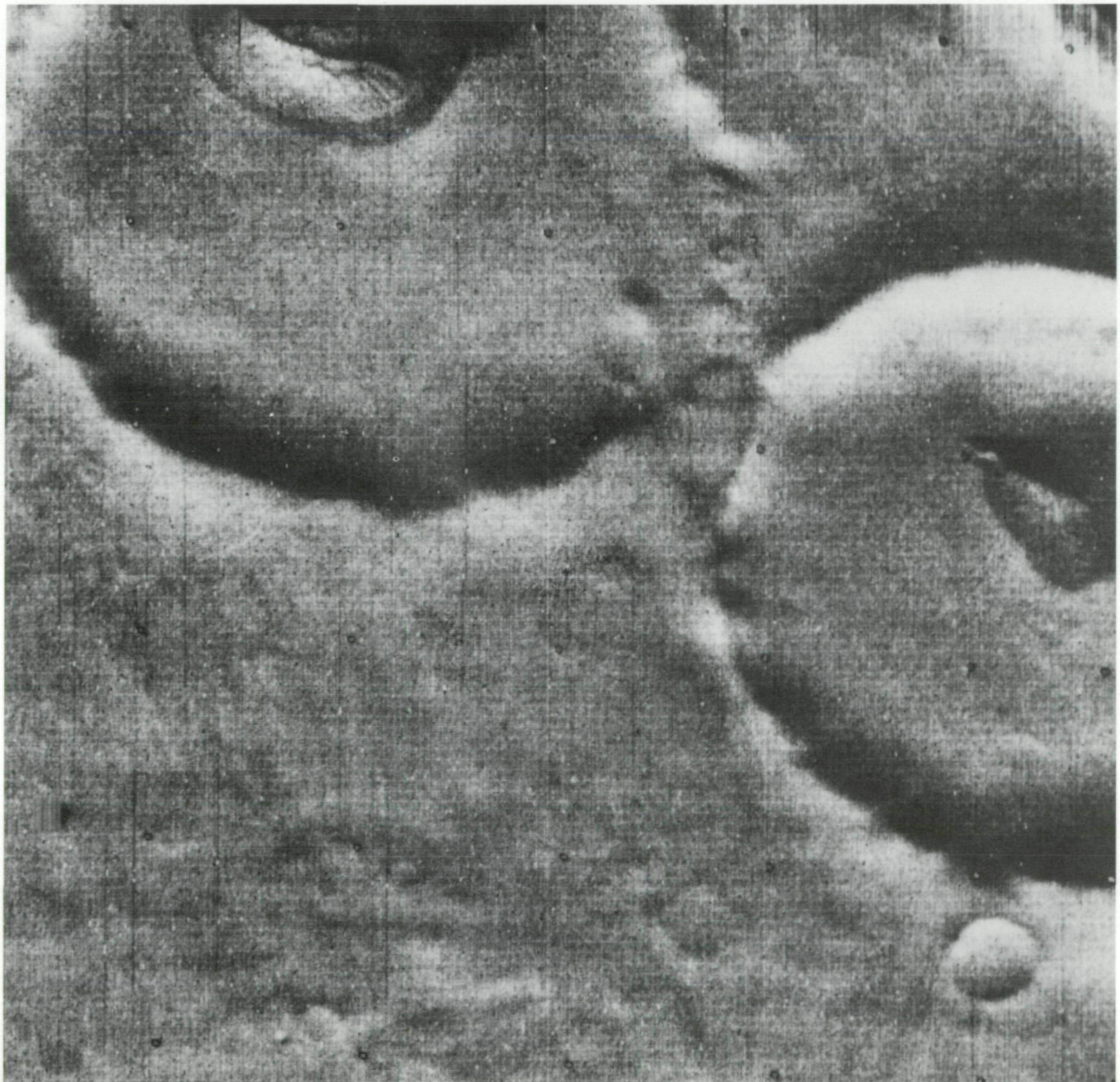
A complex pattern of delicate swirls and irregular dark tones shows in this picture of unusual terrain in Mars' south polar cap. The area covered is about 80 by 85 km. Puzzling processes, perhaps some interplay of wind deflation of layered terrain, have modified the terrain.—L. A. Soderblom

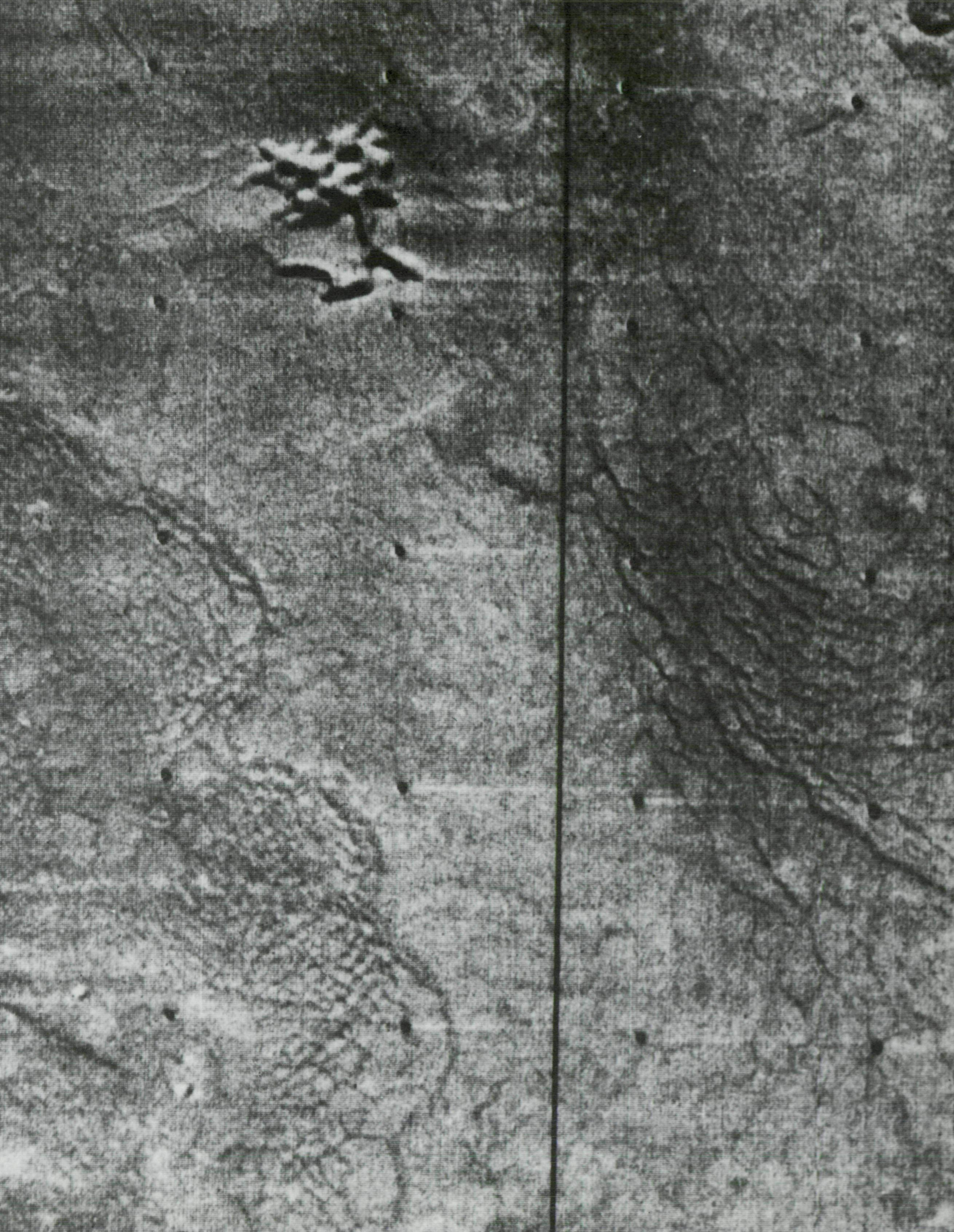
(2°S, 186°W; MTVS 4209–75)

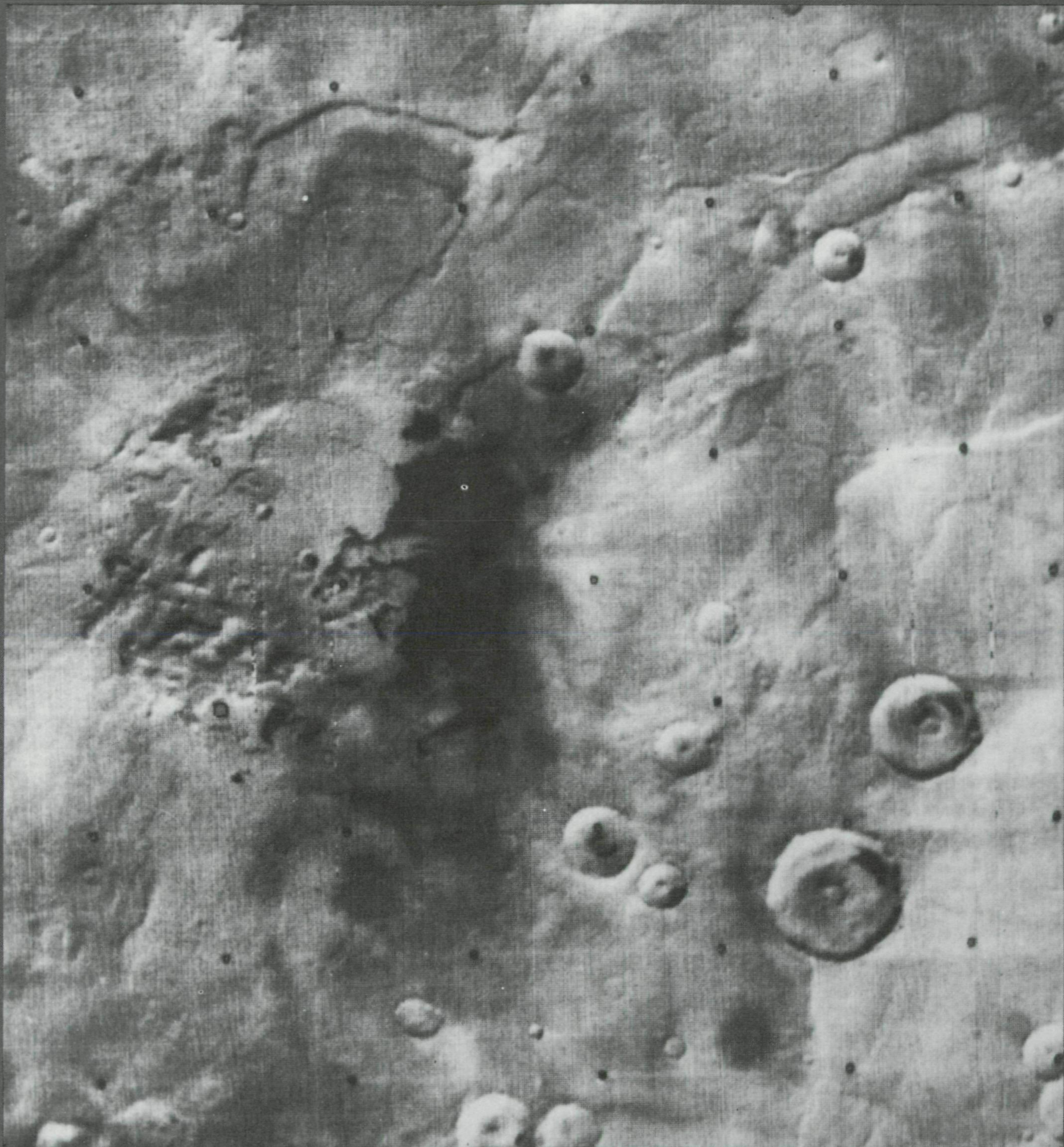
Wrinkles on the face of Mars: The smooth plains are sometimes marked by incipient collapse or flowage. It may be analogous to the landslips that occur in silty clay beds in the St. Lawrence Valley in Quebec. Collapse might come from displacement of subsurface fluids, or from melting of a permafrost layer. Here collapse occurs on the flanks of a low ridge that extends from lower right to upper left.—E. C. Morris

(67°S, 188°W; IPL 1436/130925)

Double impact craters (below), with rims and floors thinly mantled, boast striking breached volcanic cones rising from each floor. Each cone is surrounded by a dark apron that could be lava or volcanic ash.—D. B. Potter

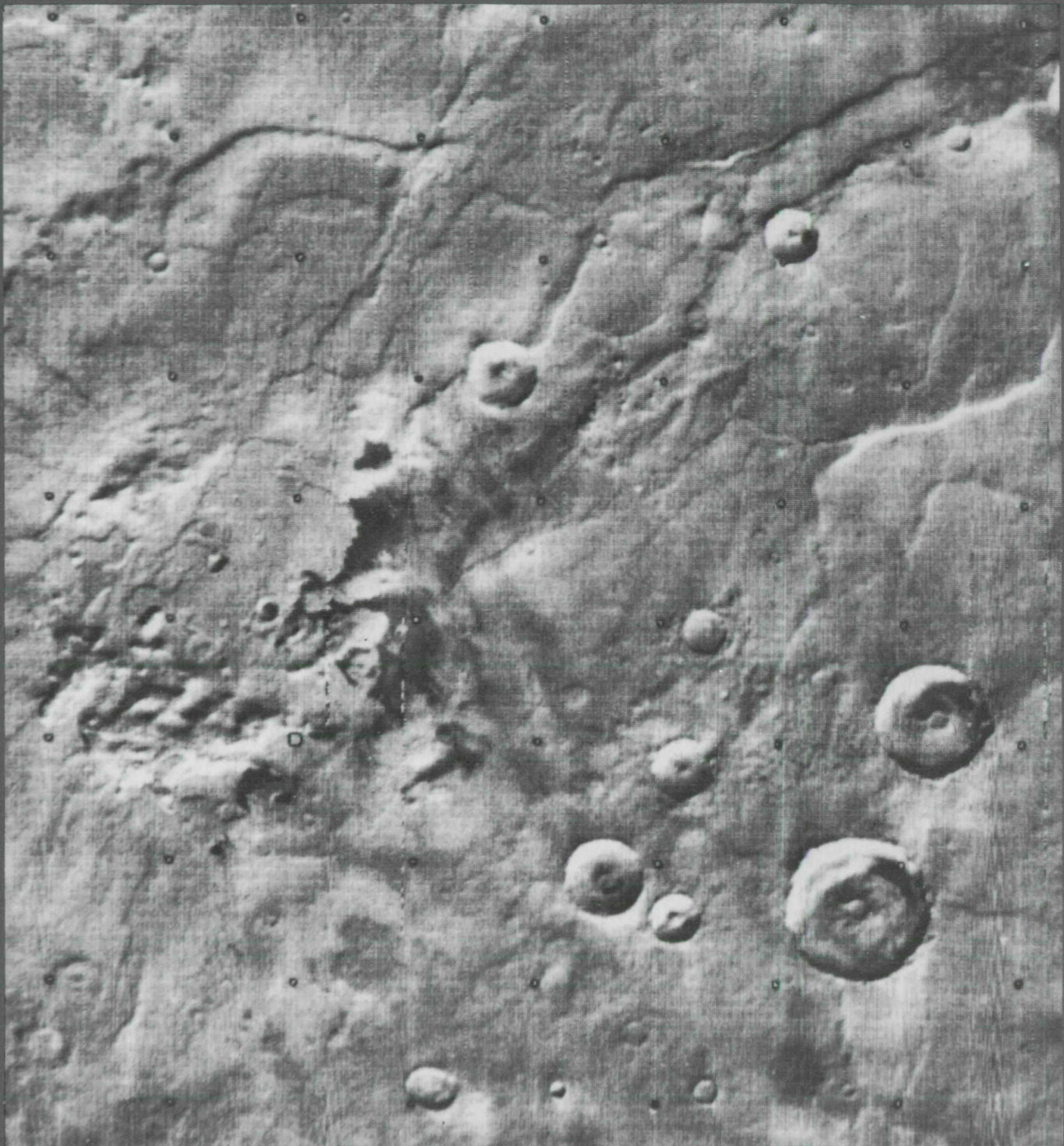




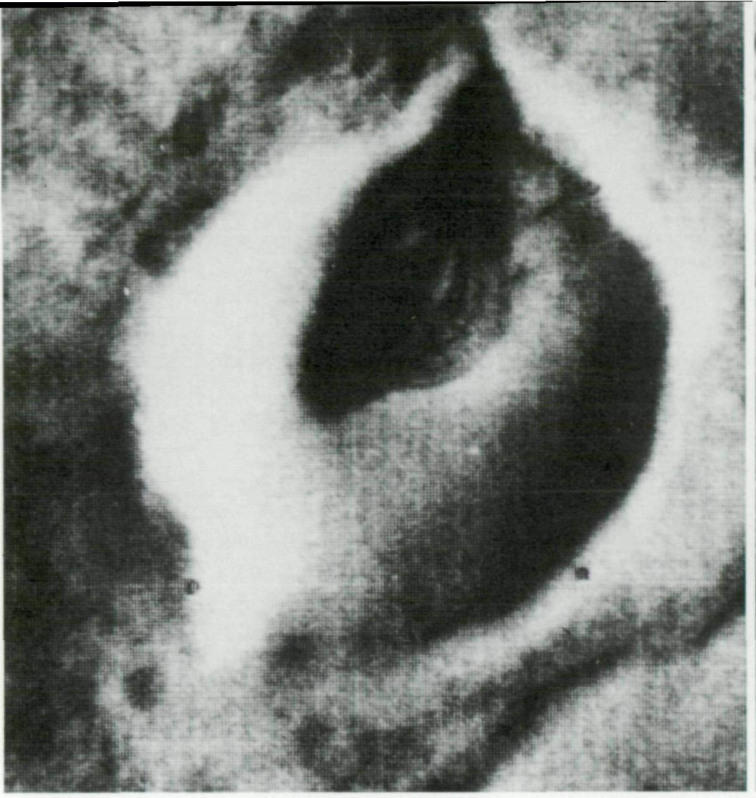
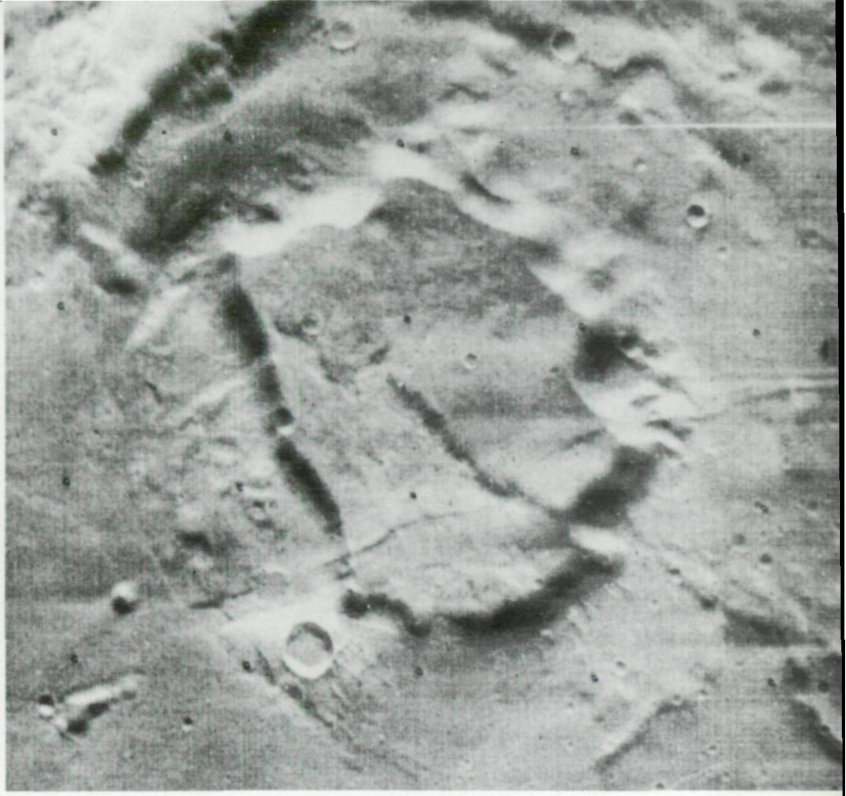


(65°S, 325°W; IPL 7225/14336, 1671/223240)

Variable features, pictured twenty days apart, offer a challenge to our understanding. View at left was acquired on February 4; one at right on February 24. Differences in light areas are probably caused in part by clouds. The changes in irregular patches of



extremely dark material may be caused by settling of dust on dark, fresh lava flows. Nearly all the craters in these pictures have a central peak or dome, some capped by small craters, which is very suggestive of volcanism.—J. E. Peterson

(54°S, 179°W; IPL 1406/225906)

The "peach pit" (above, left): the dark interior mound within this crater is of indeterminate origin. The light materials in and around the crater are probably windblown sediment.—T. A. Mutch

(38°S, 120°W; IPL 7081/154812)

This flat-topped mountain (above, right), about 20 km across, stands more than 1 km above undulating plains in the southern hemisphere. Steep sculptured slopes indicate erosional processes are causing escarpment retreat. A complex ring-like structure encircles the mountain and resembles a graben—a downdropped trough—along the left and top sides but becomes indistinct at right and bottom of the image. A low ridge runs from the center of the flat top to the lower right beyond the ring, while a fault scarp crosses the mountain and ring structure from left to right. This large mountain is of unknown origin, and does not resemble terrestrial volcanic-ring or impact features. It somewhat resembles large outliers of chaotic terrain found more than 2000 km to the east on Mars.—H. E. Holt

(35°S, 216°W; MTVS 4248–31)

Twin volcanic ranges about 20 km long have some unusual features. Tiny craters cap the peaks in each range (arrows). The southwest slope of the southwest range has an escarpment furrowed by small channels. The other slopes show mass wasting and lobes of slide material. The ranges lie within a very large crater not shown here.—J. W. Allingham

(43°S, 356°W; MTVS 4149–15)

Three unique features lie in the low resolution area shown below. They are large crater-like depressions of unknown origin. Being closed forms, they cannot have been caused by fluvial erosion, and their depth and steepness of sides rules out wind erosion as the sole cause. Some mechanism of collapse controlled by fracture systems is probably responsible, but these features are still very puzzling.—J. E. Peterson

(49°S, 358°W; IPL 7205/184628)

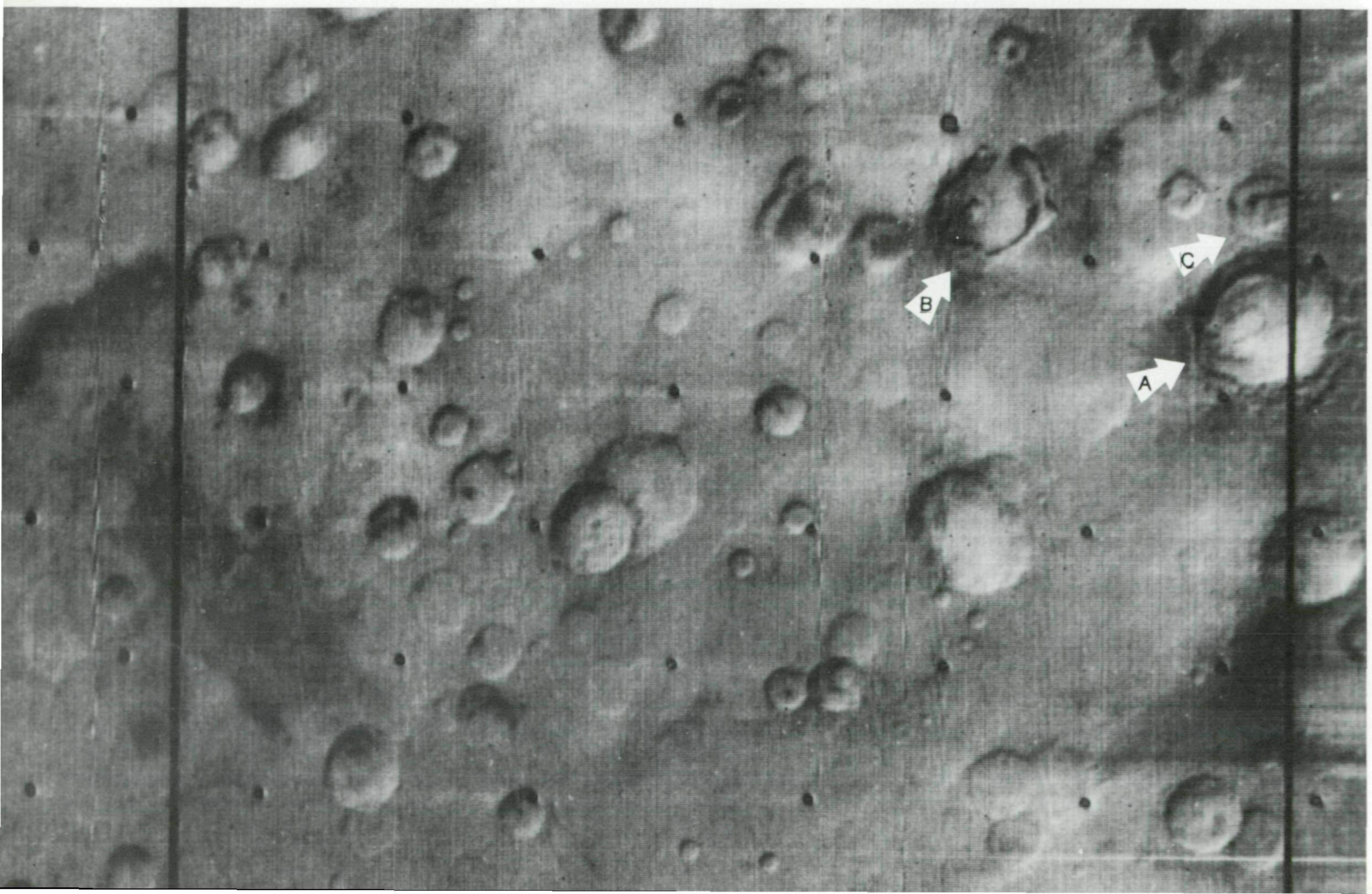
Curving within a 100-km crater is a 60-km long depression, the end of which is shown here (right, top). Its walls are very steep, and there appears to be a flat-lying resistant layer at its rim. It is about 7 km wide at the arrows. Clouds partly obscure the picture.—J. E. Peterson

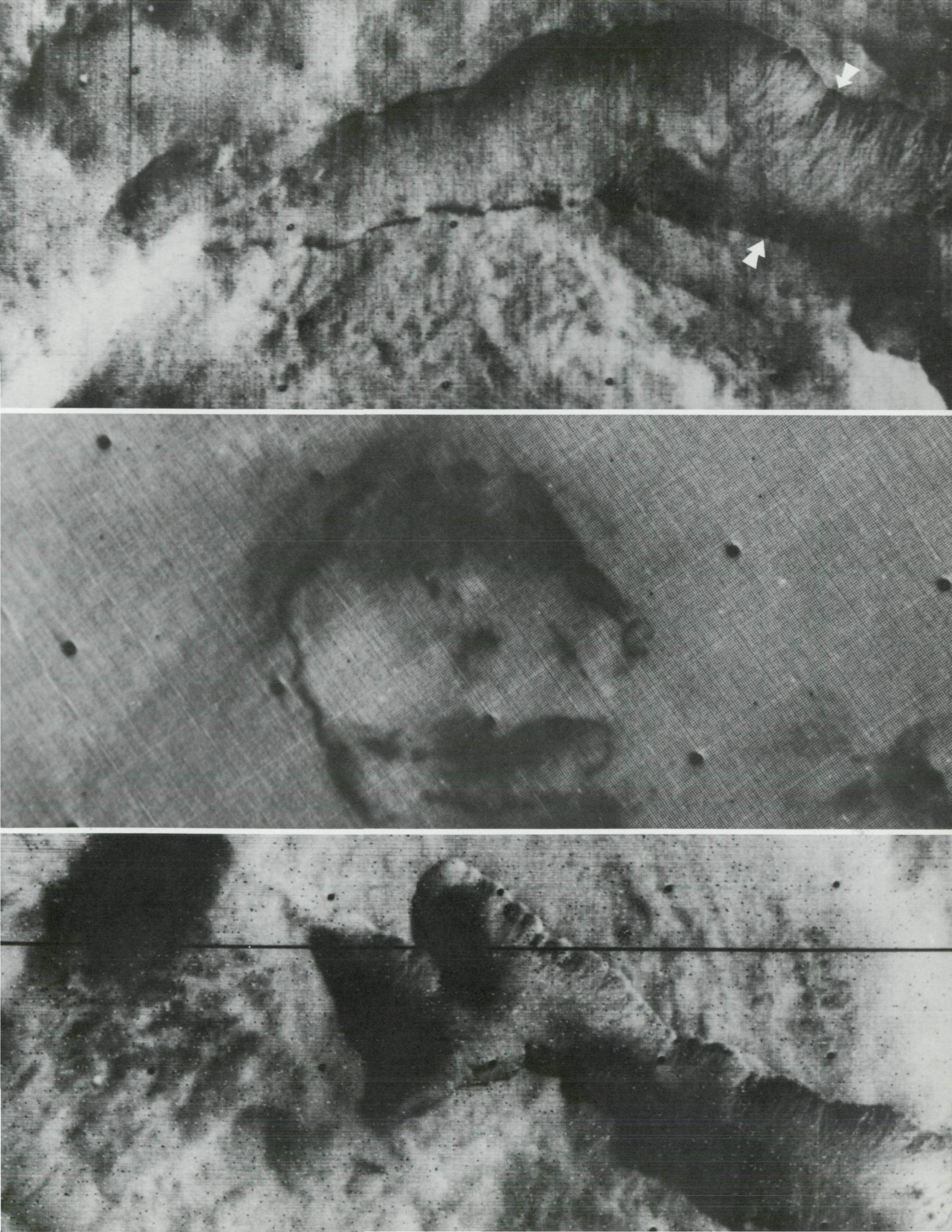
(45°S, 356°W; IPL 1943/201557)

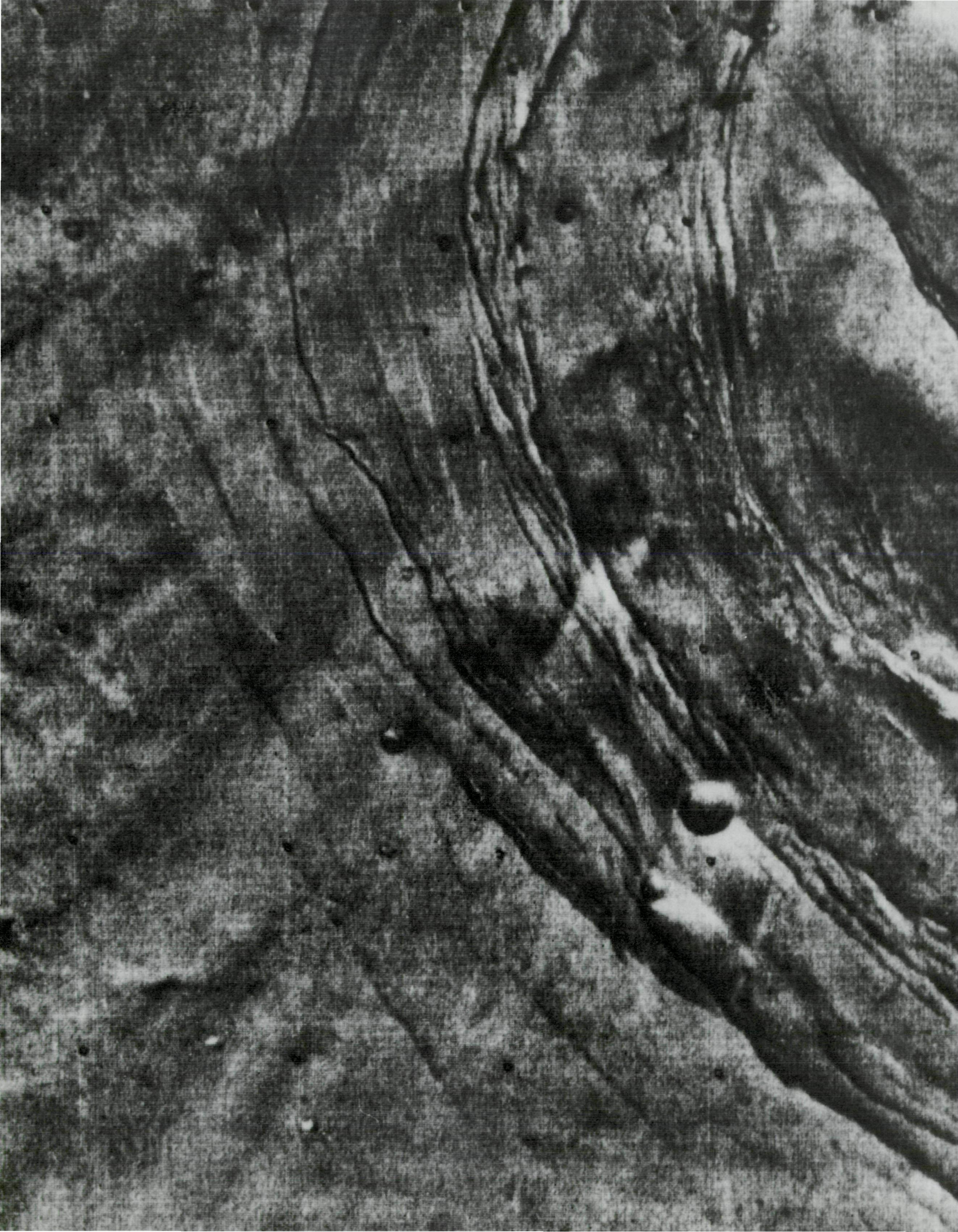
A central plateau in this unique 85-km diameter feature is connected to the surrounding plains (right, center). The steep-walled depressions are somewhat sinuous but follow a roughly circular outline. This picture was acquired near the end of the global dust storm and is somewhat obscured.—J. E. Peterson

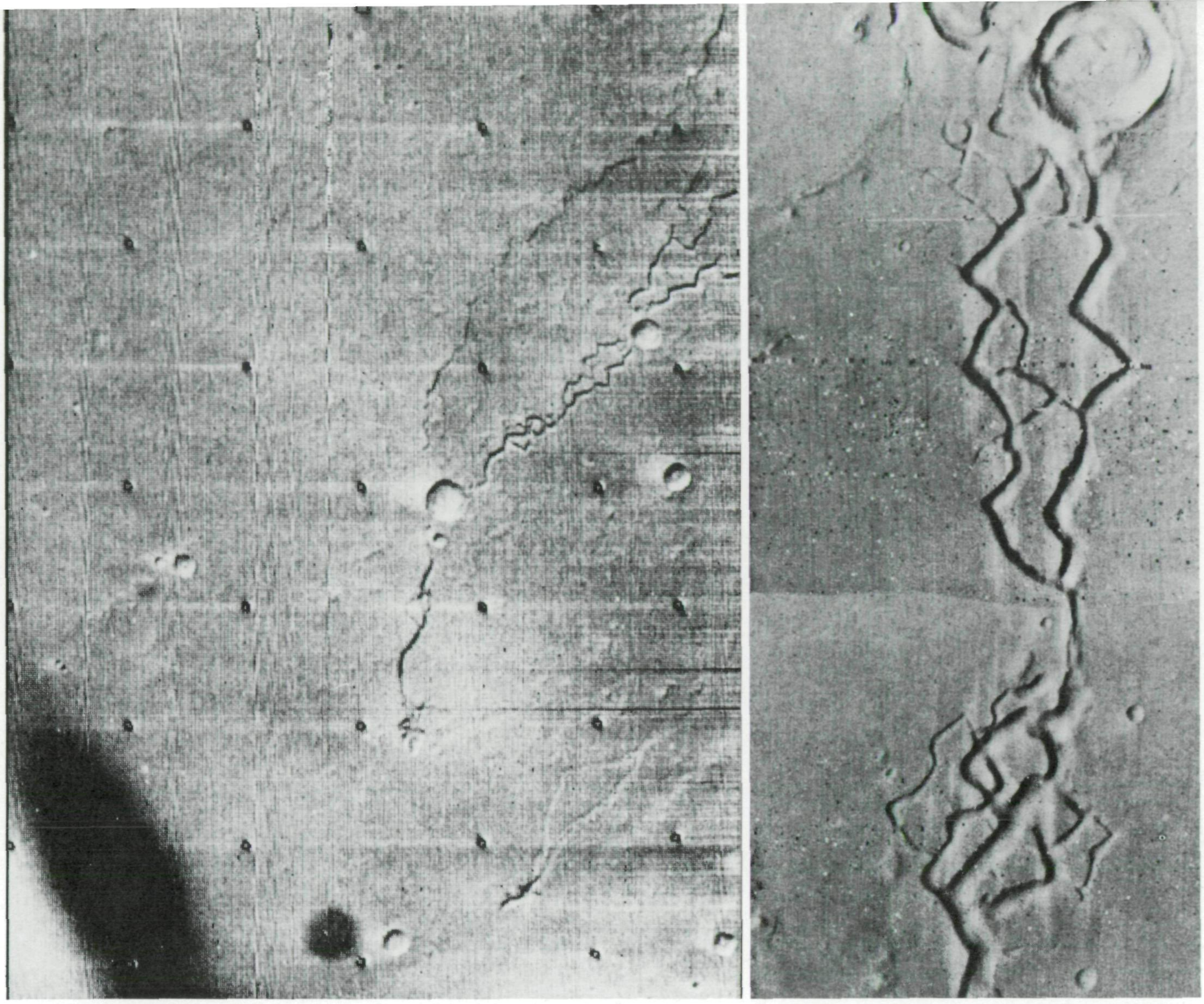
(50°S, 357°W; IPL 7455/235030)

A deep linear depression is terminated (right, bottom). It is about 5 km wide at its narrowest point. The sides are very steep, with debris-avalanche chutes on the walls, but the bottom seems fairly smooth and rounded in cross section. Again, clouds apparently obscure this picture somewhat. This gash extends nearly across a large crater.—J. E. Peterson









(20°N, 235°W; IPL 1765/212715)
(18°N, 235°W; IPL 7256/131906, 7256/133526)

This strange feature (above), Hephaestius Fossae, is located in the Elysium Planitia. It is a system of branching troughs approximately 525 km long and 75 km wide. The elongate shadow of Mars' moon Phobos can be seen in the low resolution photo (the round black spot is a camera artifact). In the high resolution mosaic, the general pattern of the troughs indicates fracturing as a more likely cause than fluid flow. Individual troughs are up to 2 km wide, and considerable erosion by wind may have broadened them.—R. S. Saunders

(9°N, 293°W; MTVS 4266–35)

An enigmatic collapsed depression (left) occurs in the region of Syrtis Major Planitia. The structure here has the crisp arcuate scarps that characterize the volcanic calderas of the Tharsis Montes. But it may also be a karst-like feature formed by removal of deeply buried ice or other subsurface materials. (A karst is a region of sinks and ridges overlying limestone.)—T. A. Mutch

16
Similarities: Mars, Earth, and Moon

It is impossible to look through the thousands of images of Mars returned by Mariner 9 without discovering features reminiscent of those on our native planet. When a match-up is made by geologists having professional familiarity with the Earth's features, as on the following pages, the similarities can be striking. The Moon, liberally photographed during the first years of space exploration, also has details that appear similar to those that Mariner 9 revealed on Mars. Sometimes laboratory simulations can help bridge the gap between the apparent and the known, as when wind-tunnel experiments on model craters seemingly duplicate erosion patterns seen on the surface of Mars.

For two reasons these analogs may be less surprising or significant than they seem. In a sense it is small wonder that Mars, Earth, and Moon do, in fact, look somewhat alike, particularly if you examine the Earth through geologists' eyes. Windblown features are easily identifiable in, for example, Texas, Idaho, and New Mexico. Evidence of volcanism can be seen in Arizona, faulting in California, stream erosion throughout the United States, stratified deposits in Utah, and glacial features in Alaska. The Hawaiian Island complex is comparable in some respects to the volcanic region of Mars near Olympus Mons.

We should be cautious and not make the mistake of assuming that resemblances—limited as they are to the physical appearance of surface features—are proof of true similarities. It can be a profound mistake to assume that similar-looking features actually originated and evolved in a like manner. Without a doubt, future exploration of Mars will show that some of the dynamic processes that shaped the surface of Mars were the same as those that caused terrestrial features. Geologists are now conducting research programs in the southwestern United States, Peru, and Antarctica to collect data that may cast light on the question of whether Mars and Earth evolved similarly. Theoretical calculations and laboratory experimentation will provide the quantitative information needed to understand the physics of these processes.

The exciting thing about comparative planetology is that it will permit us to unfold the lost part of the Earth's history, now largely obliterated by erosion, mountain building, and other processes. A full understanding of the past is a reliable way to accurate prediction of the future. This work can help predict the nature and course of future atmospheric evolution, answering the disturbing question of whether the Earth's environment is destined to grow similar to the environment of Venus or Mars. Questions like these can only be approached by comprehending the secrets of the planets in our solar system. Comparative planetology is the starting point for an understanding of the physical future of planet Earth.

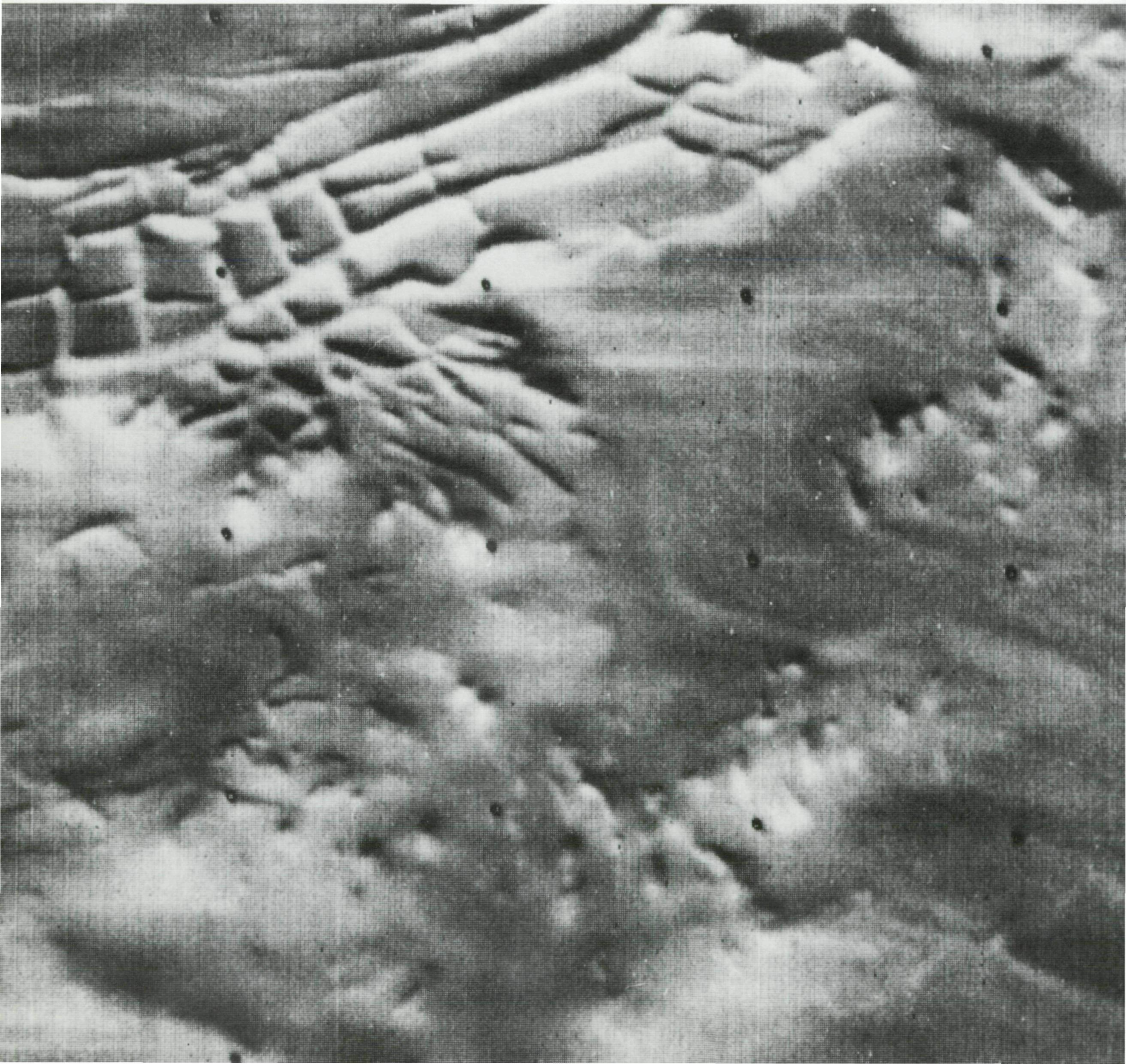
In the meantime, the analogs on the following pages suggest that the old saying may have to be modified to "It's a small solar system."—S. E. Dwornik

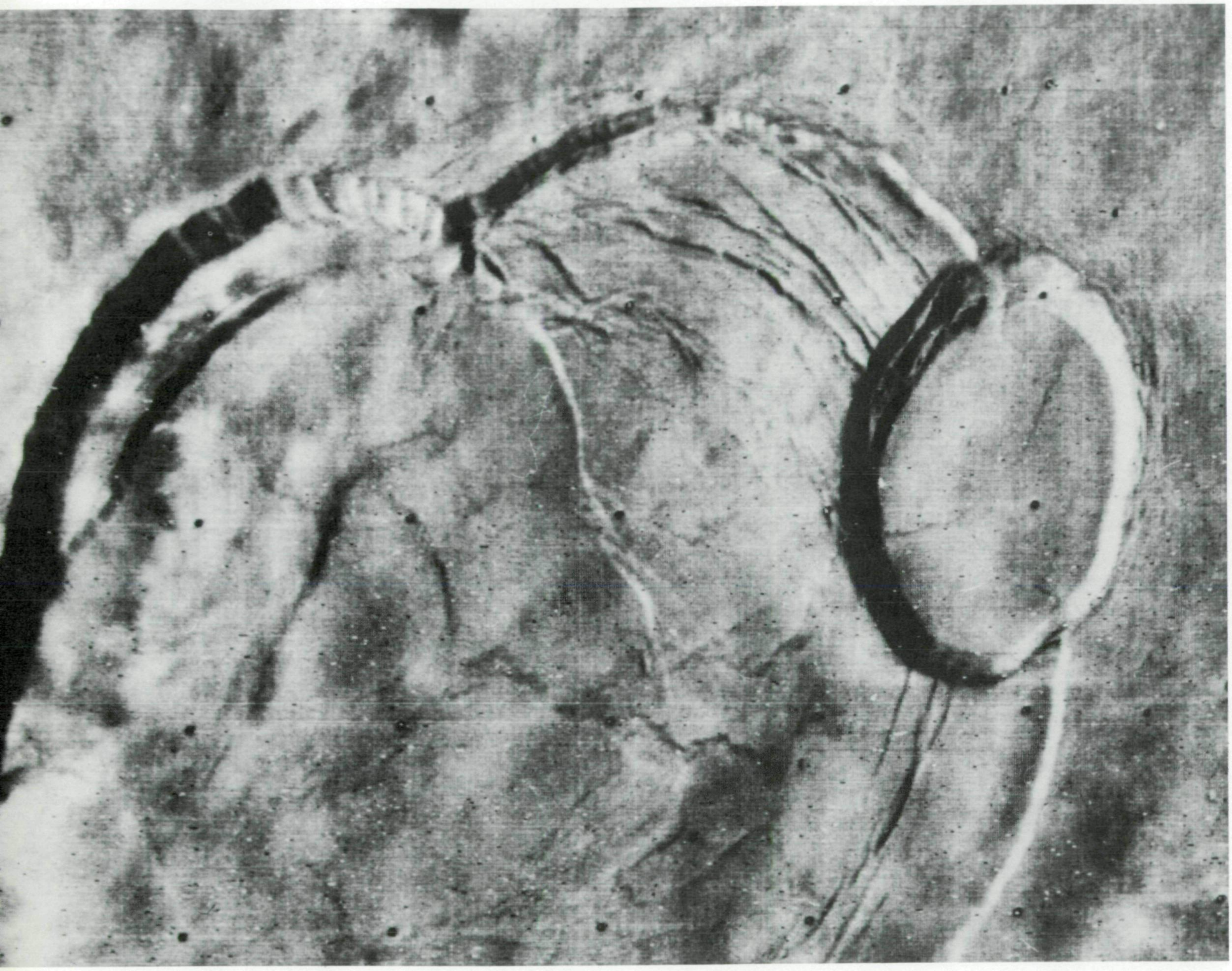
(14°N, 142°W; MTVS 4174–75)

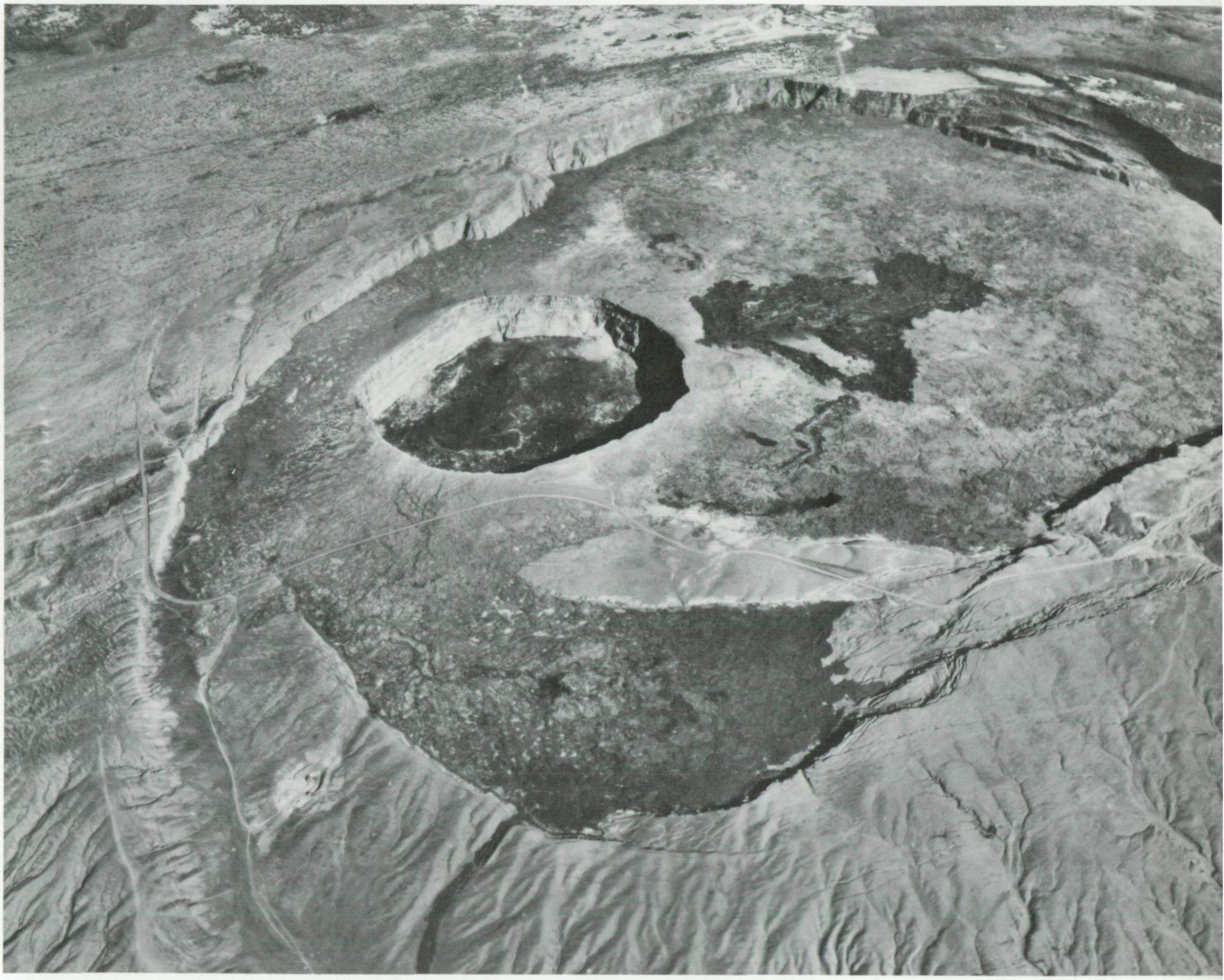
Wind-produced streamlining of a part of the complexly structured aureole around Olympus Mons is seen above. These elongate ridges are 10 to 15 km long and 3 to 5 km wide. They are parallel to numerous smaller grooves and roughly elliptical pits that are also the probable result of wind erosion. The crests of many of these ridges occur sharp and keel-like in appearance; their ends are sharply tapered. These ridges occur in terrestrial deserts such as Iqa Valley in Peru (right) where they are several kilometers in length and hundreds of meters high. The Iqa Valley ridges have been cut by strong sea winds that funnel almost daily into this virtually rainless valley. The layered rocks here are relatively soft, Tertiary sediments uplifted from the sea by faulting since the onset of aridity in this region.—J. F. McCauley

(81°S, 64°W; IPL 1417/160341)

Another probable result of wind erosion (below) is seen in this unusual and complex array of linear, interconnected reticulate ridges in the south polar region of Mars. (The picture is about 45 km wide.) A superficial resemblance to ancient ruins led to their informal appellation as "Inca City" during the Mariner 9 mission. A more mundane explanation is that this feature almost surely represents yet another variant of the landforms produced by wind on Mars. The origin of the reticulate pattern itself is unknown; igneous or clastic dikes or indurated fracture zones are all possibilities. As can be seen in the photo from the almost rainless coastal desert of Peru (right), similar patterns can be produced by selective wind scouring. (The image is about 2½ km across.) The more resistant dikes or fractures abrade less rapidly than the softer surrounding material and thus stand above the surrounding plains like the walls of a ruined city.—J. F. McCauley

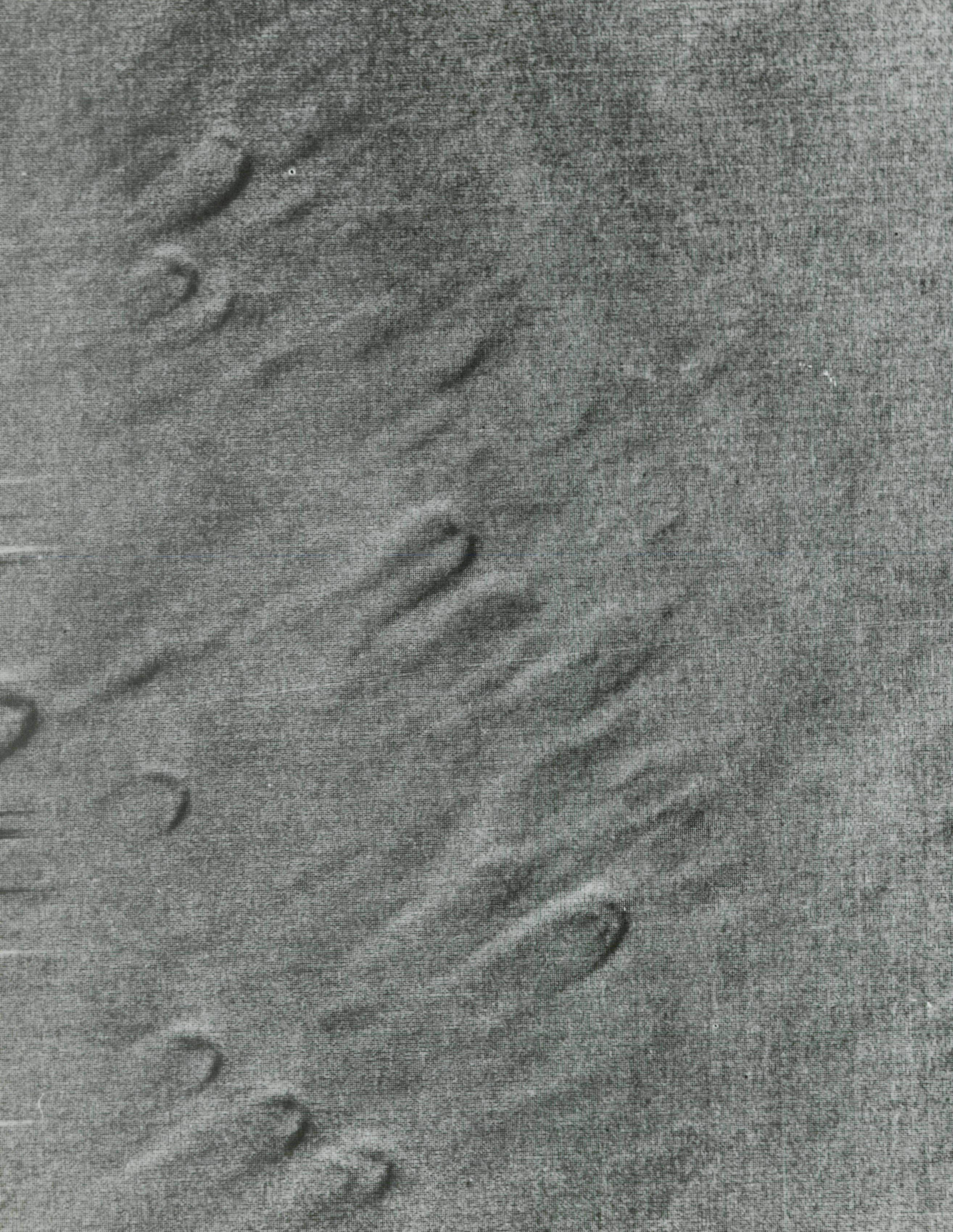


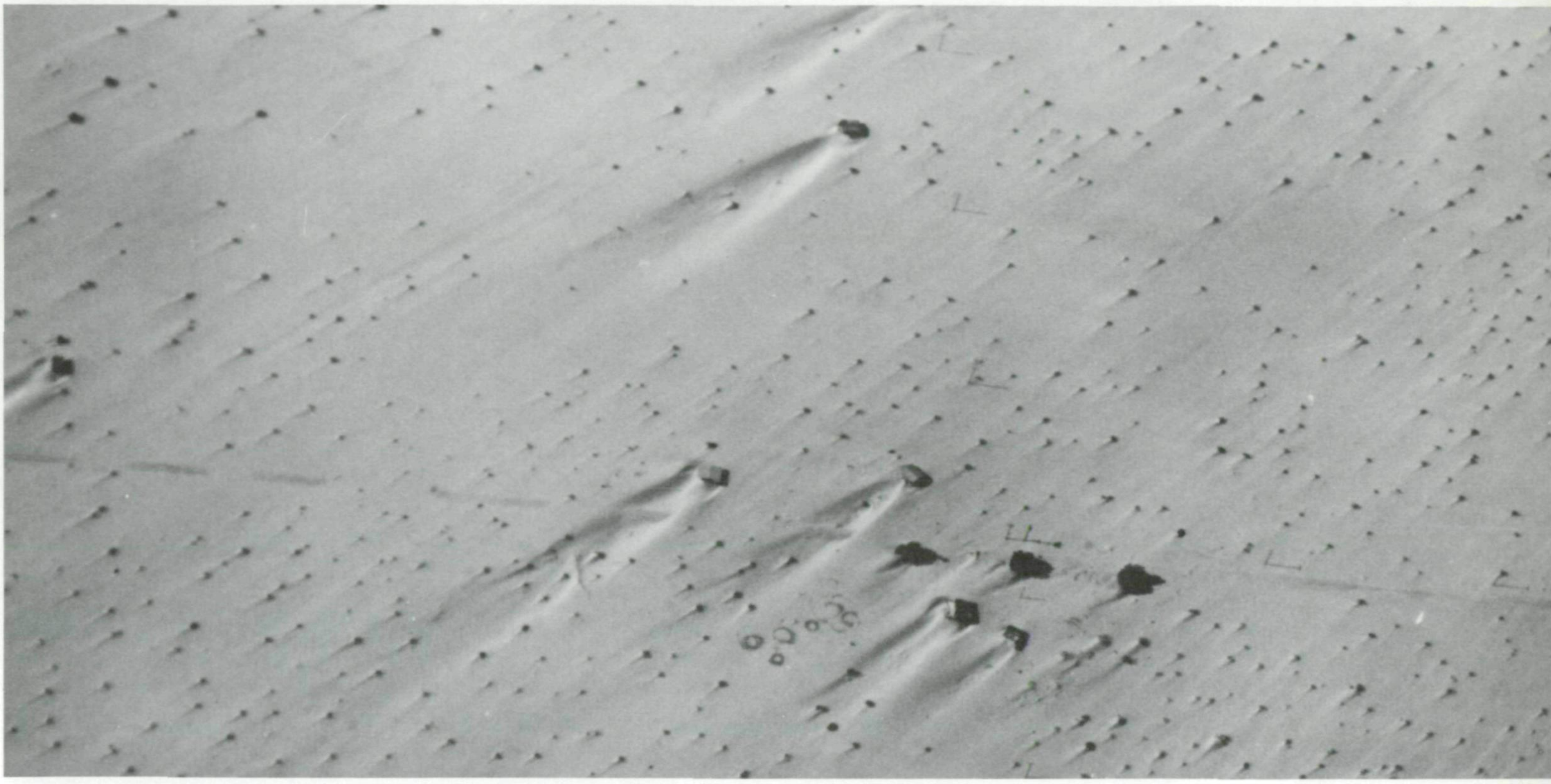




(18°N, 133°W; IPL 1406/164237)

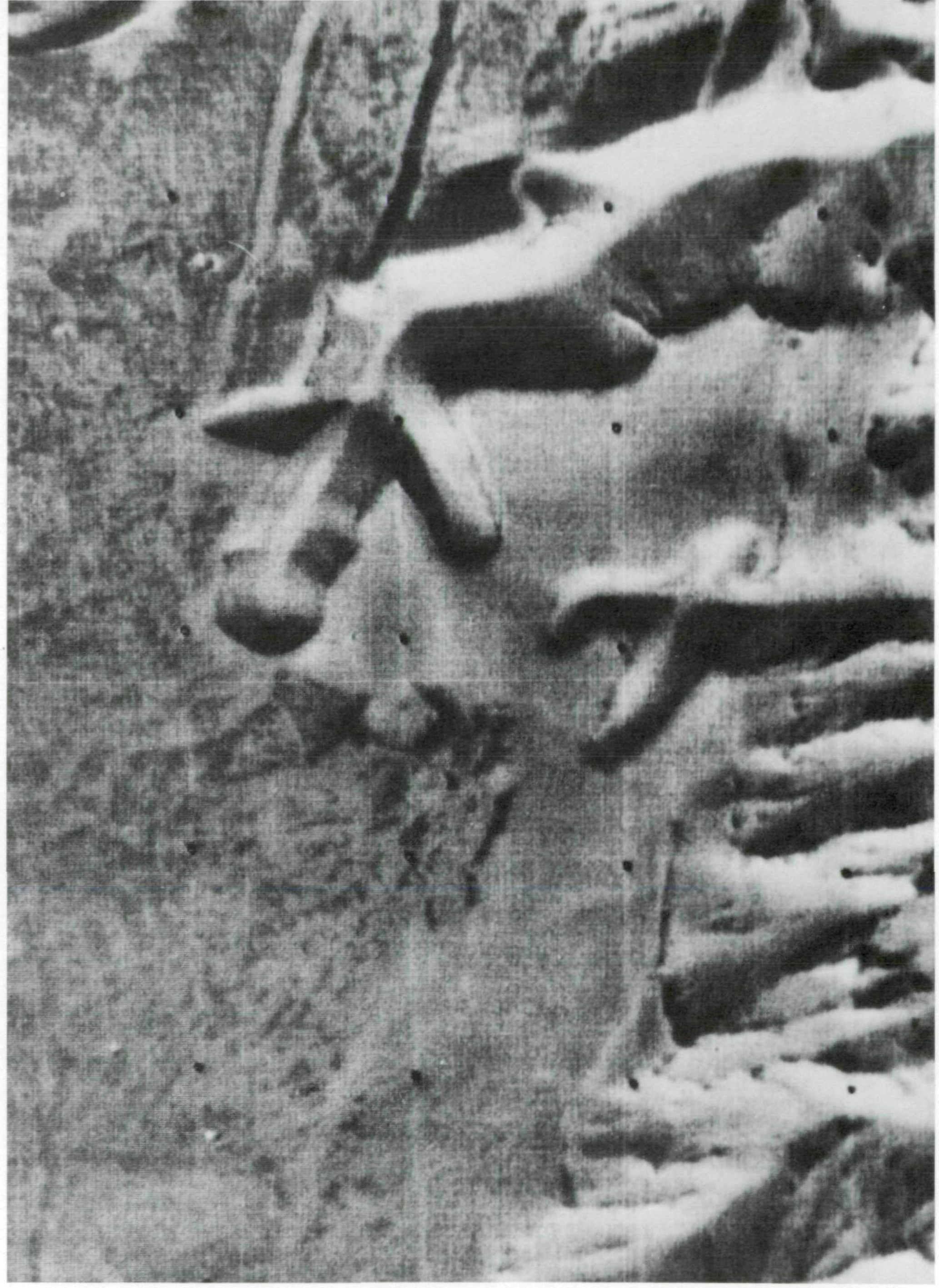
Calderas on Earth are created by the collapse of the surface as lava is erupted or when it drains away at depth. Here repeated collapse events produced complexes of older large calderas surrounding a smaller younger one. Shown are Kilauea in Hawaii (above) and Olympus Mons (left) on Mars.—K. A. Howard





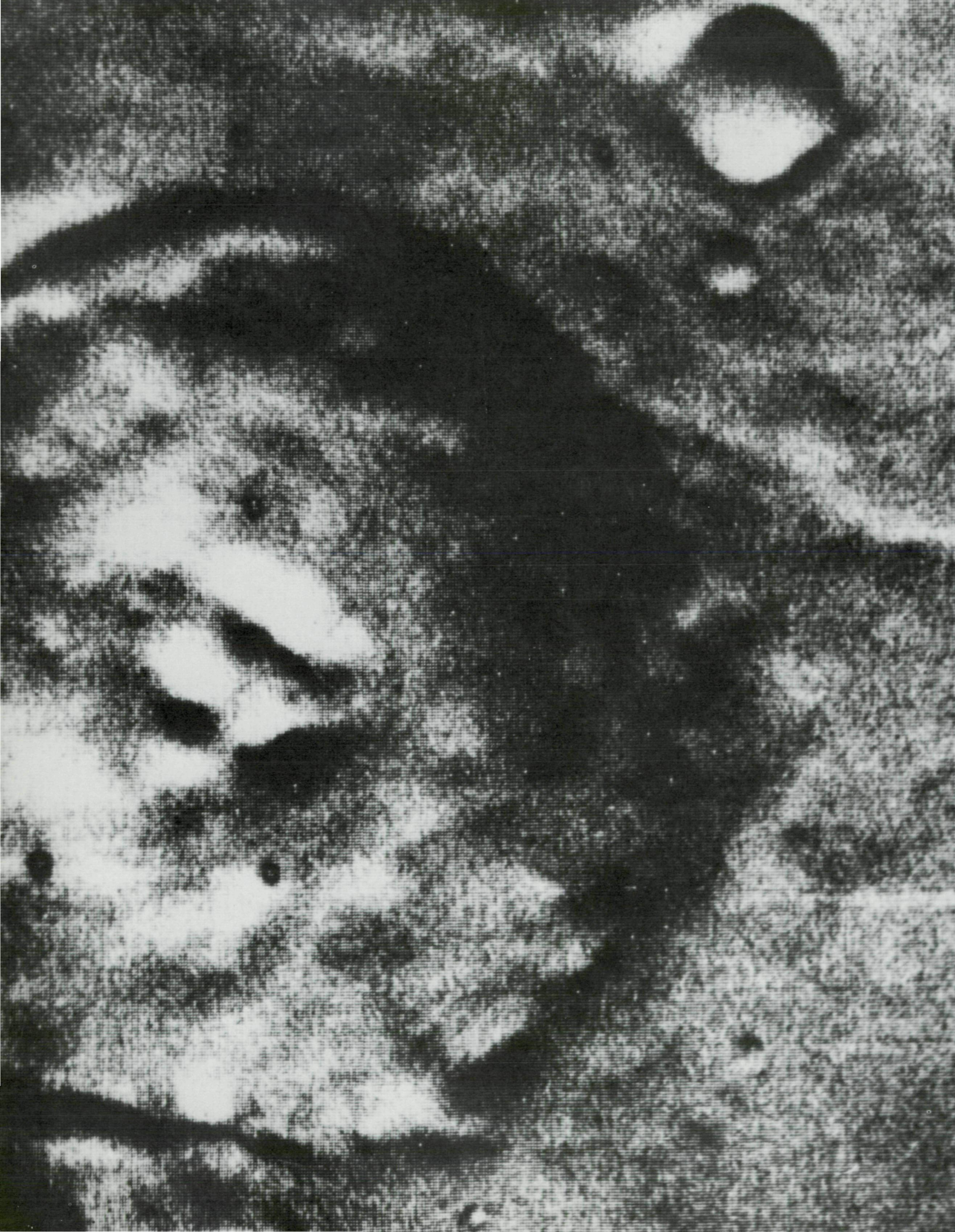
(1°N, 157°W; MTVS 4254–55)

U-shaped depressions are often produced by the wind in the lee of rocks or other topographic obstacles. These occur where an active, mobile sheet of loose-moving sand is present on the surface. Deposition of the sand tends to occur on the upwind side and the flanks of the obstacle and an erosional blowout or depression occurs on the downwind side. These features may be controlled in great part by the presence of partially buried crater rims just now poking above the sand blanket. Picture at left is a high resolution image of the Amazonis Planitia on Mars; blowouts shown are up to 3 km long. The picture above is a low-altitude aerial photo taken in the Coachella Valley, California, where the blowouts are tens of meters long and occur in the lees of abandoned shacks.—J. F. McCauley



(6°S, 84°W; IPL 1356/114237)

Stubby, relatively deep gullies without well developed tributaries are seen in the photo at right of an alluvial wash on the shore of Lake Mead, Arizona. They are developed in loosely consolidated material that fails by slumping and soil flowage due to changes in the lake level and degree of saturation of the soil. A similar stubby, poorly developed dendritic pattern (above) is seen in many tributaries of the Valles Marineris on Mars, suggesting that they may have formed by some type of sapping or soil flowage process rather than by water collected runoff from rainfall during an earlier pluvial episode on Mars.—J. F. McCauley

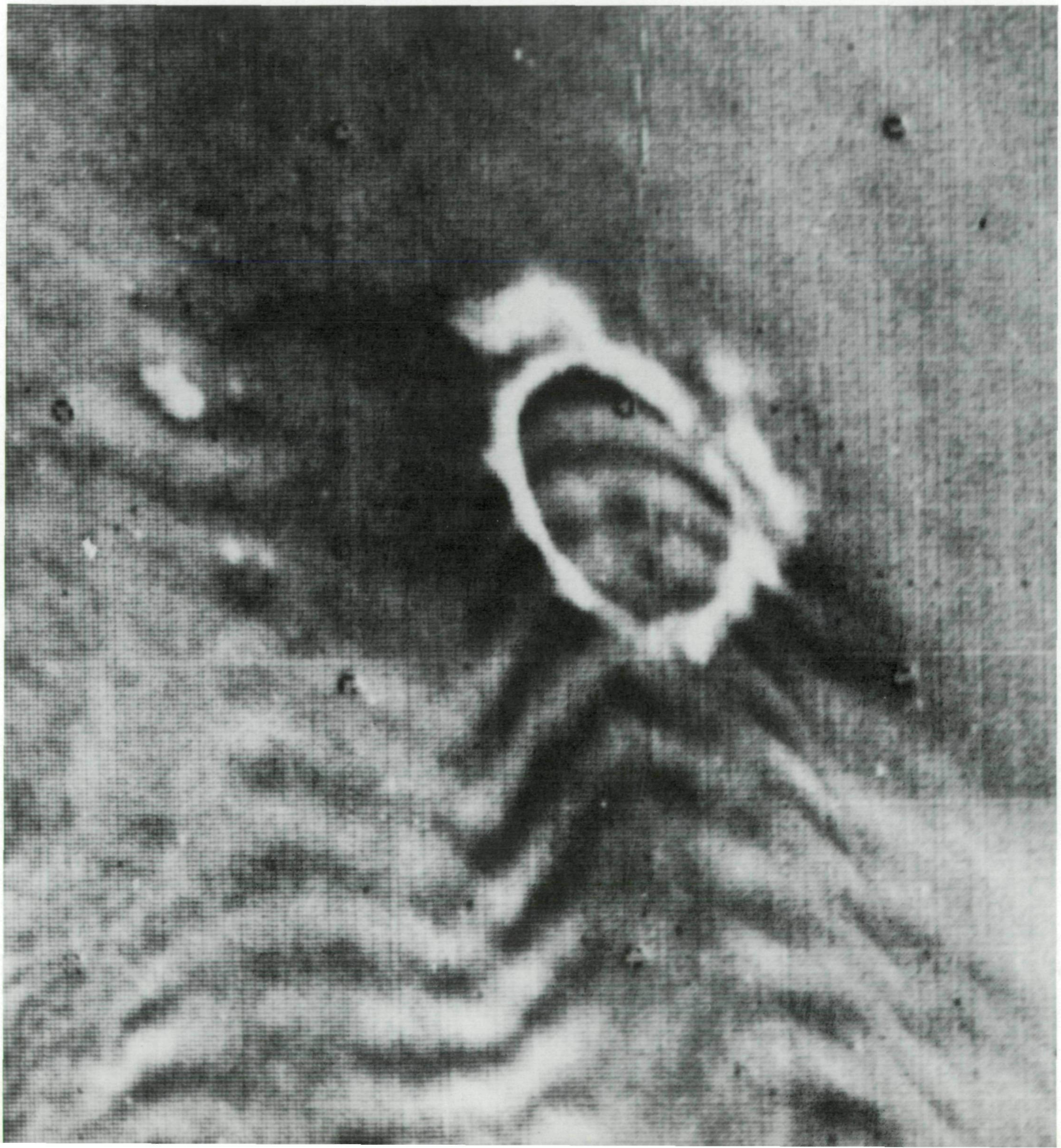


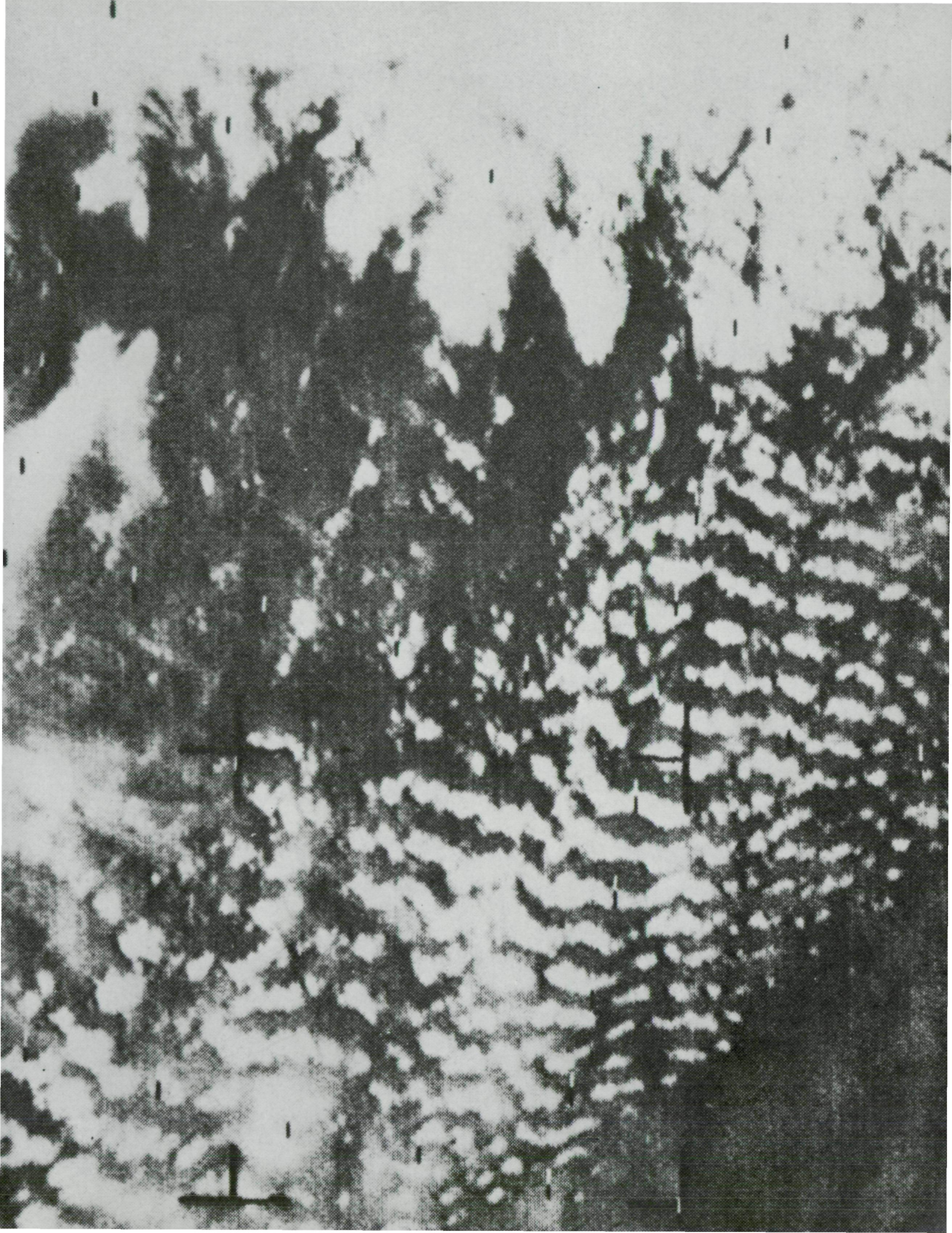
(2°N, 314°W; MTVS 4178–60)

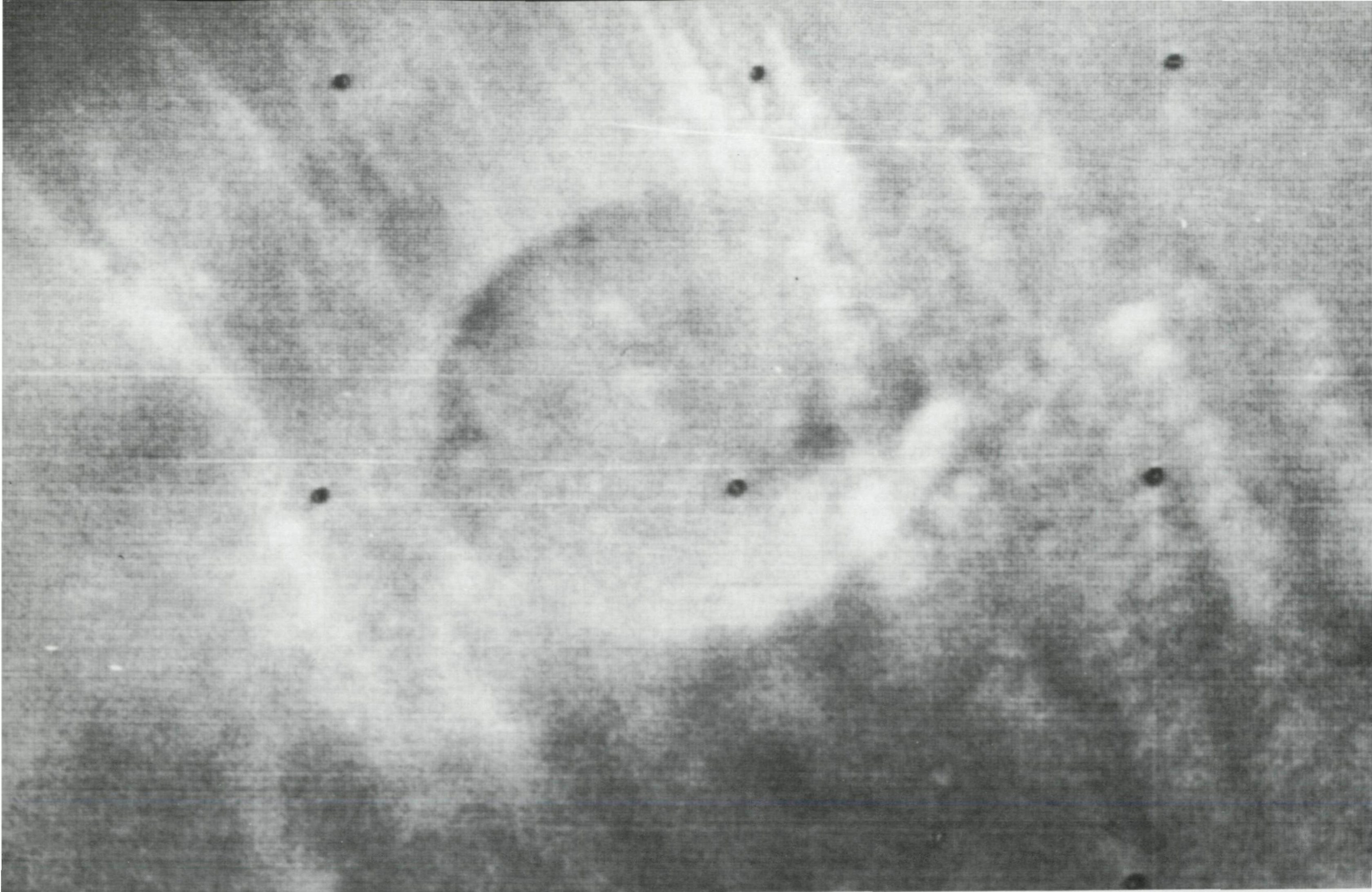
Central peaks in craters or basins, though widely assumed to have been formed by impact or volcanic processes, can also arise from wind deposition. While the origin of the peak in the Mars crater (left) is as yet unproven, in the basin shown above at Bruneau, Idaho, the center is dominated by a large sand-dune complex maintained by wind blowing in two main directions.—J. D. Murphy, J. S. King, and R. Greeley

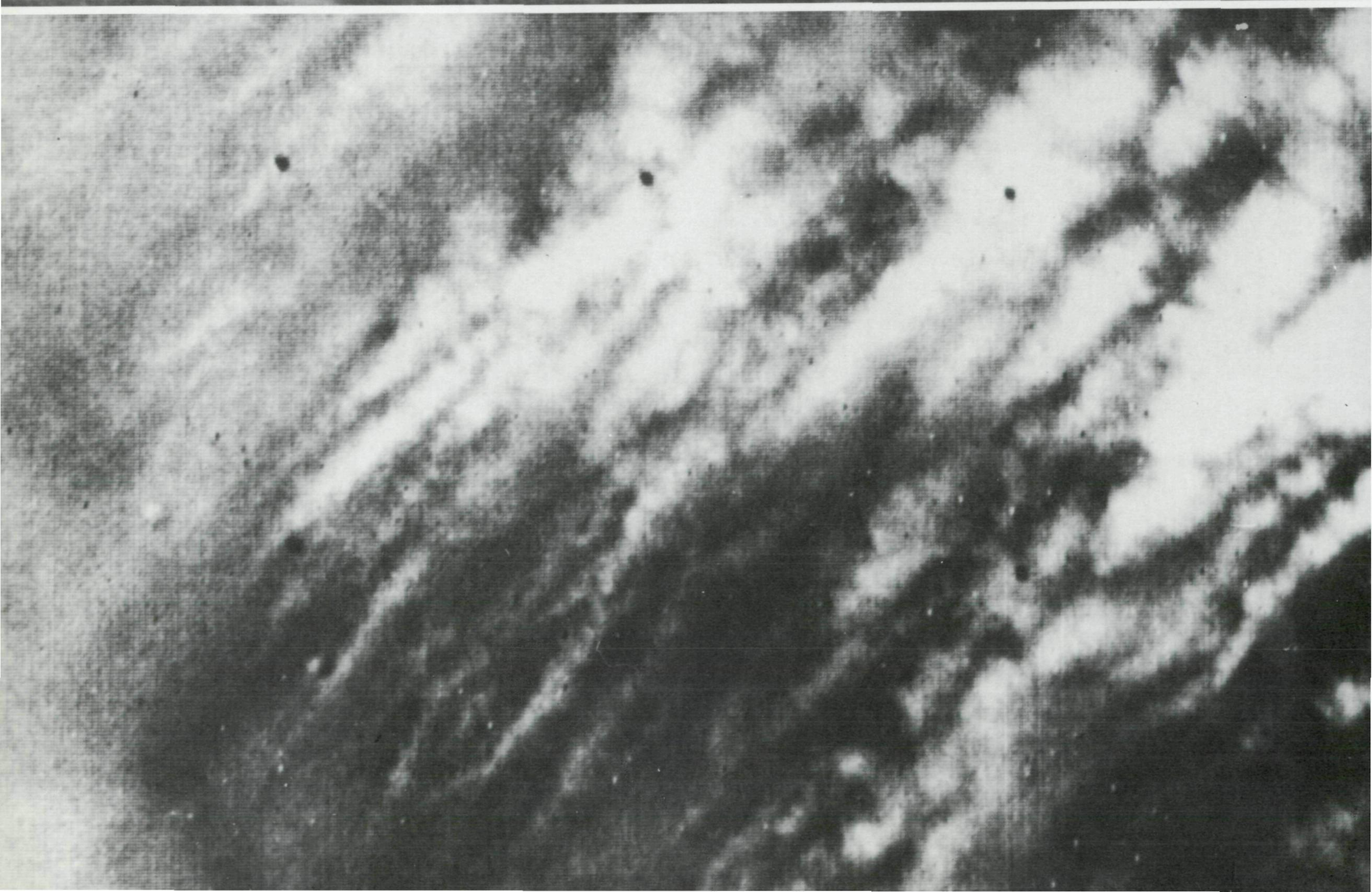
(56°N, 16°W; IPL 1643/194728)

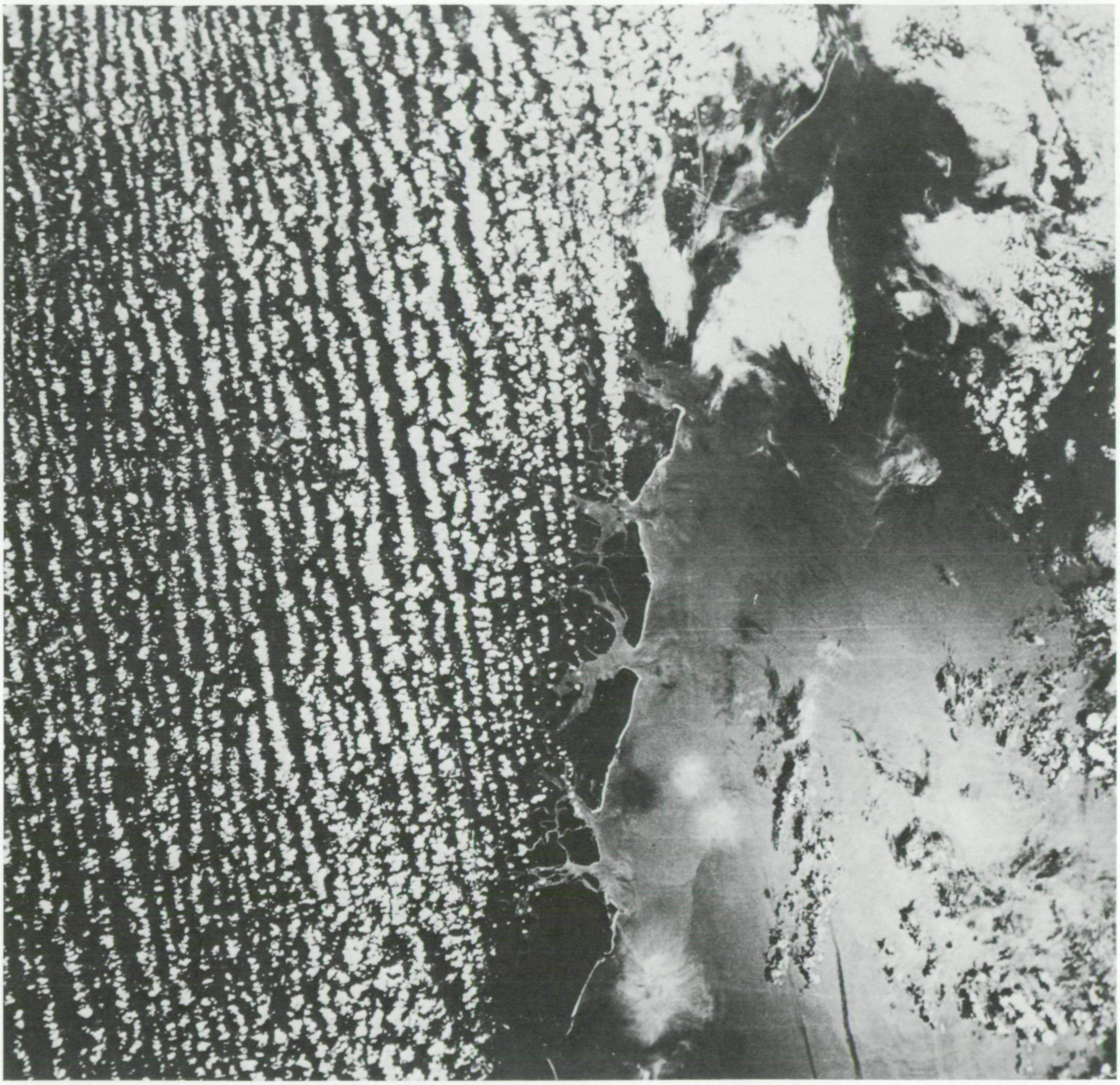
Clouds on Mars can resemble those on Earth. Flowing past a frost-rimmed crater 90 km in diameter, northern winter winds form clouds of a characteristic lee-wave pattern on Mars (below). At right, a similar lee-wave pattern was seen by Nimbus 1 downstream of the Andes over Argentina.—C. B. Leovy





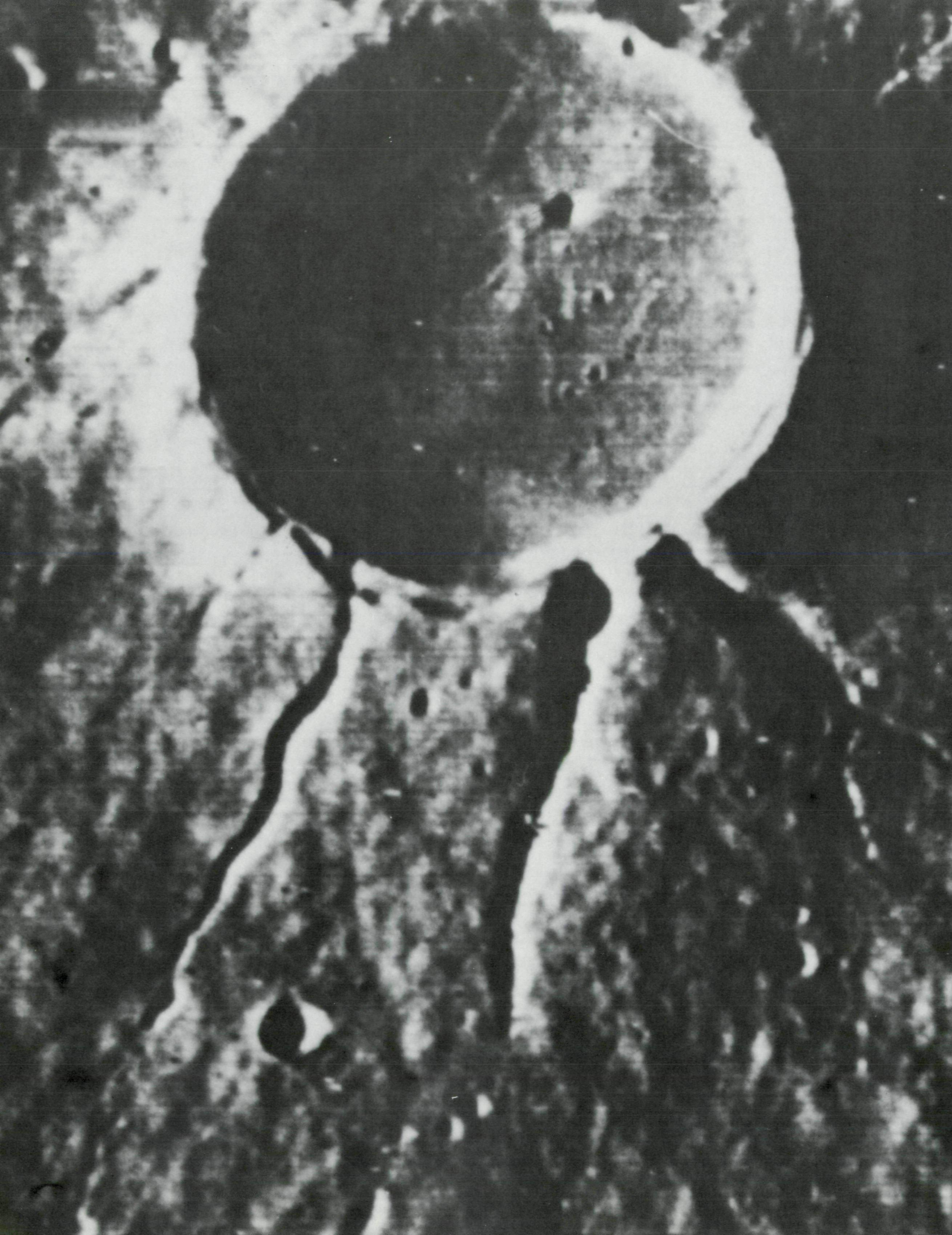


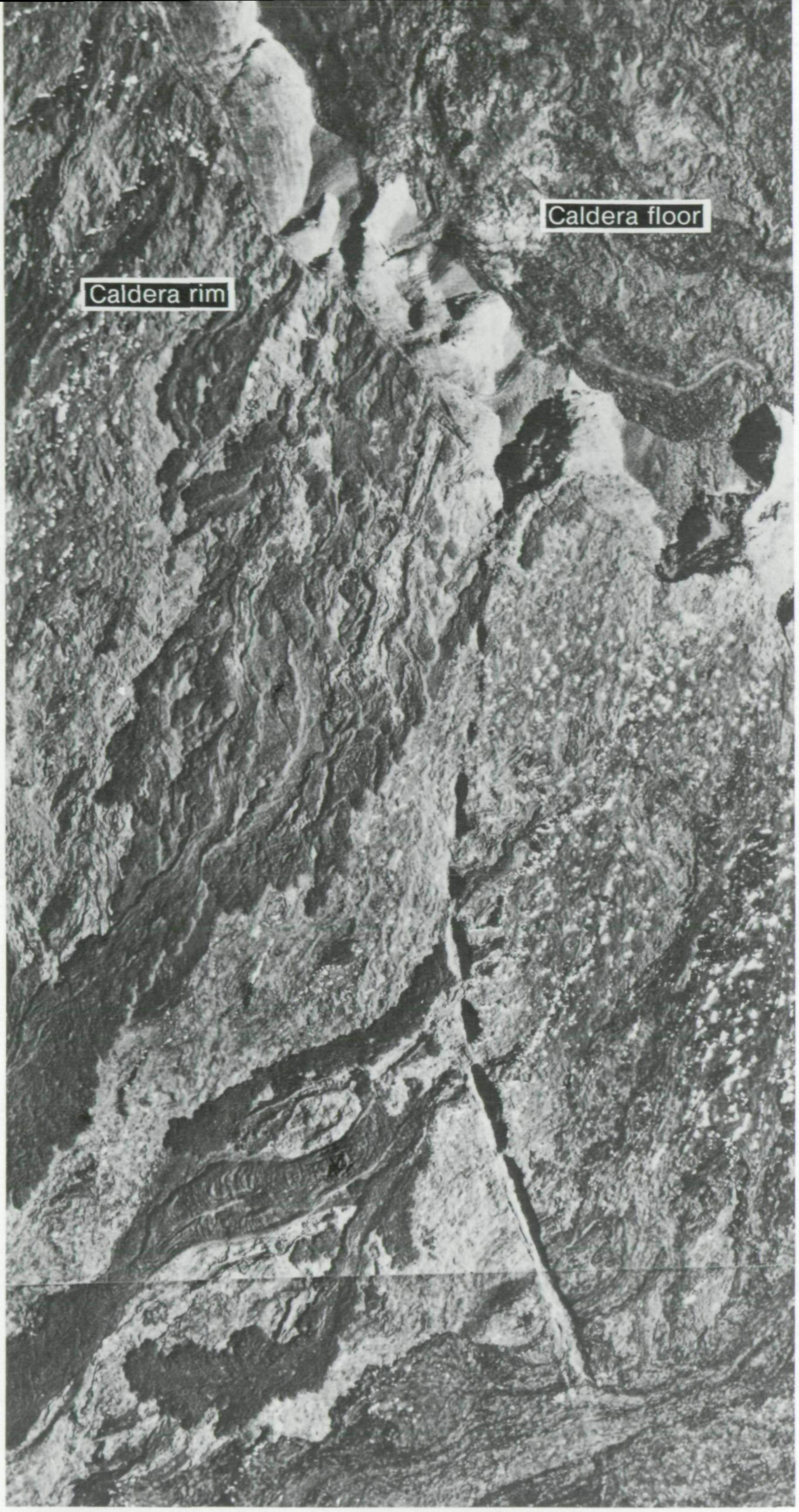




(60°N, 270°W; IPL 1431/193738)
(60°N, 178°W; MTVS 4248–98)

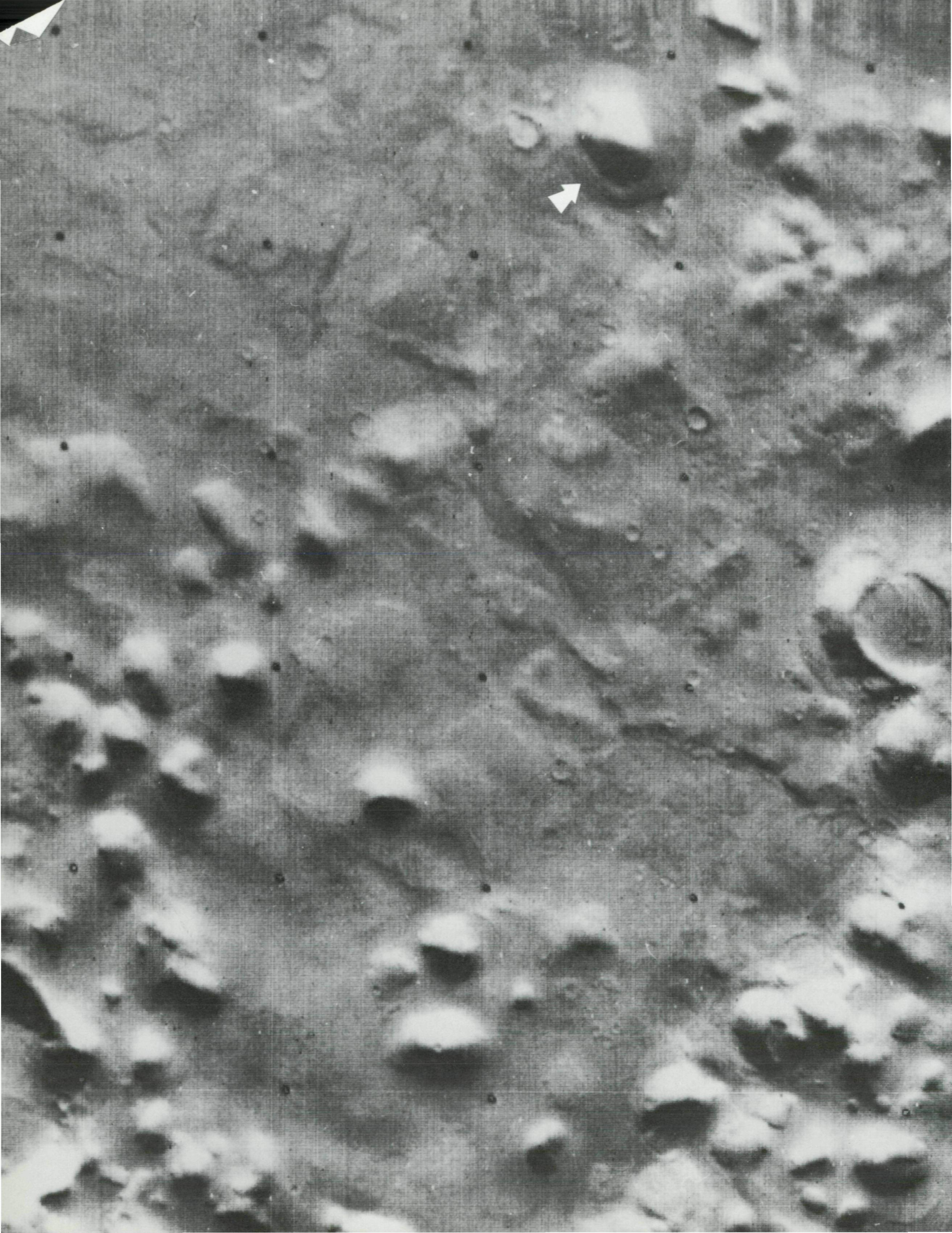
Long cloud lines on Mars (left, top) are formed by convection as cold polar atmosphere rushes southward over warmer ground. The convection creates long spiraling plumes downwind, with clouds forming on the rising part of the spiral. At left bottom, similar cloud lines begin to break up into large convective clusters in another part of the martian north polar region. Above, an Apollo photo shows cloud lines on Earth, where relatively cool air from the Atlantic flows northward over the warm ground of South Carolina.—C. B. Leovy





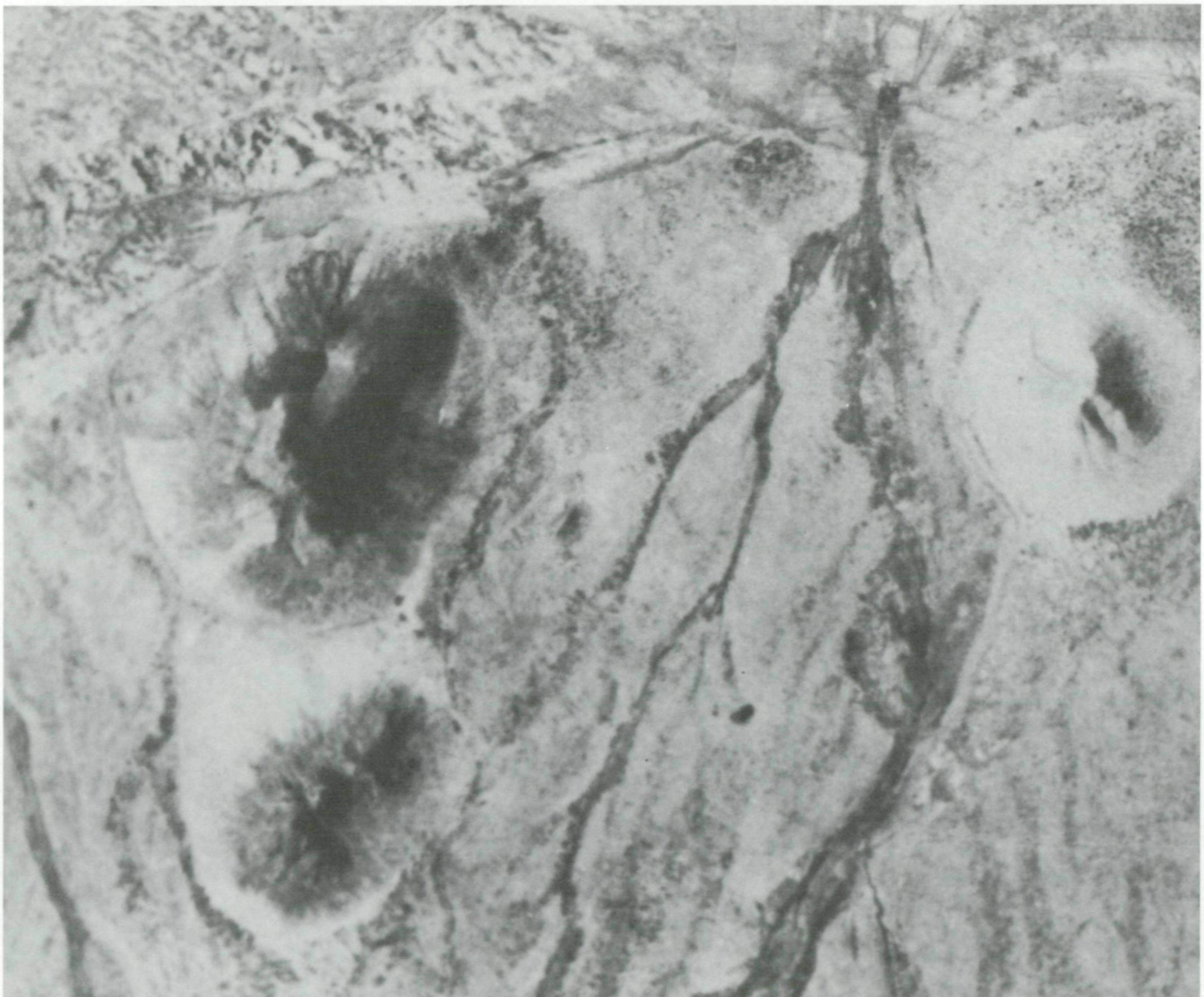
(25°N, 213°W; MTVS 4298–40)

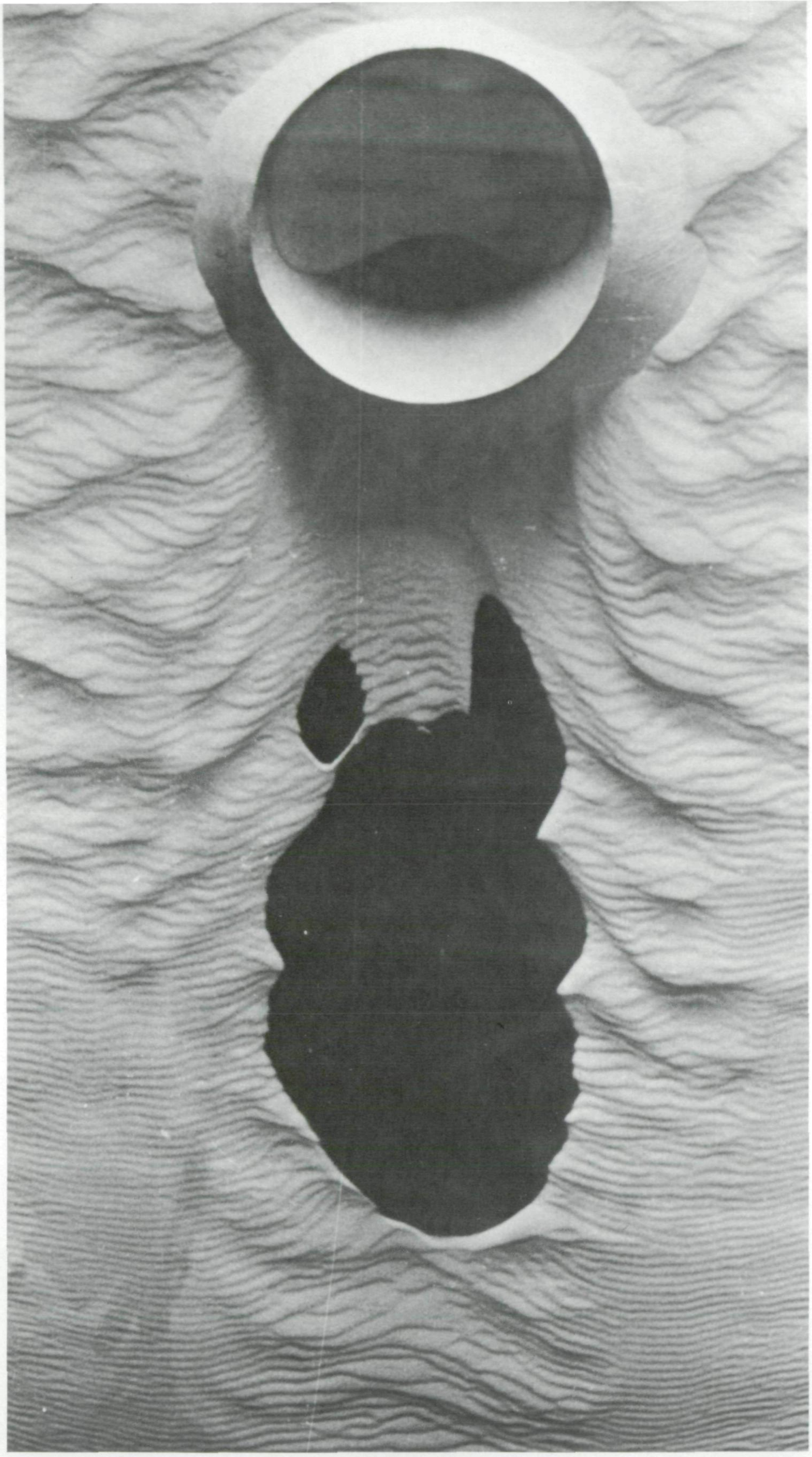
Radial structures about this summit caldera in the Elysium Planitia of Mars (left) are interpreted as fractures that have been modified by lava flows. Compare them with the similar fracture from the rim of the Mauna Loa caldera, pictured above. (A small segment of the caldera rim is in the upper part of the picture.)—R. Greeley



(38°N, 196°W; MTVS 4244–76)

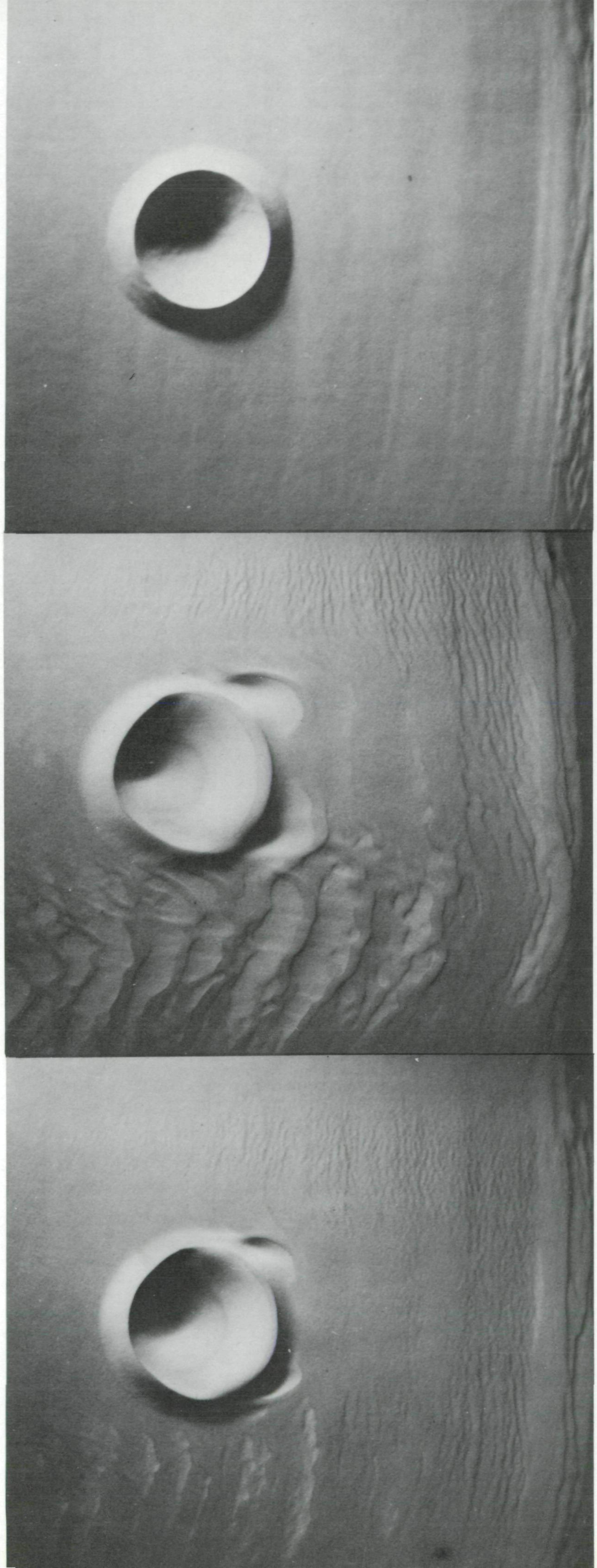
Martian inselbergs near Phlegra Montes (left) and terrestrial inselbergs in New Mexico (below). In dry climates these eroded remnants of mountains are sometimes surrounded by bajadas (debris sheets). A good example is seen in the upper right of the Mars photo. Most terrestrial mountains are eroded gradually and smoothly both by wind and rain; debris is washed evenly onto the surrounding area. However, in deserts infrequent but voluminous cloudbursts are responsible for the transport of great quantities of rock materials that accumulate as a depositional apron around the inselberg in Animas Valley, New Mexico. Bajada-like features are also seen on Mars; their origin is uncertain since there is no present fluvial activity. Perhaps these debris aprons are related to the desiccation that is evident from dry stream channels. The bajadas also may have formed simply by gravity as the debris slid down the slope to flat areas. The terrestrial inselbergs shown here are approximately 1 km in diameter; the remnant in the upper right of the Mars photo is about 10 km in diameter including the bajada.—W. E. Elston

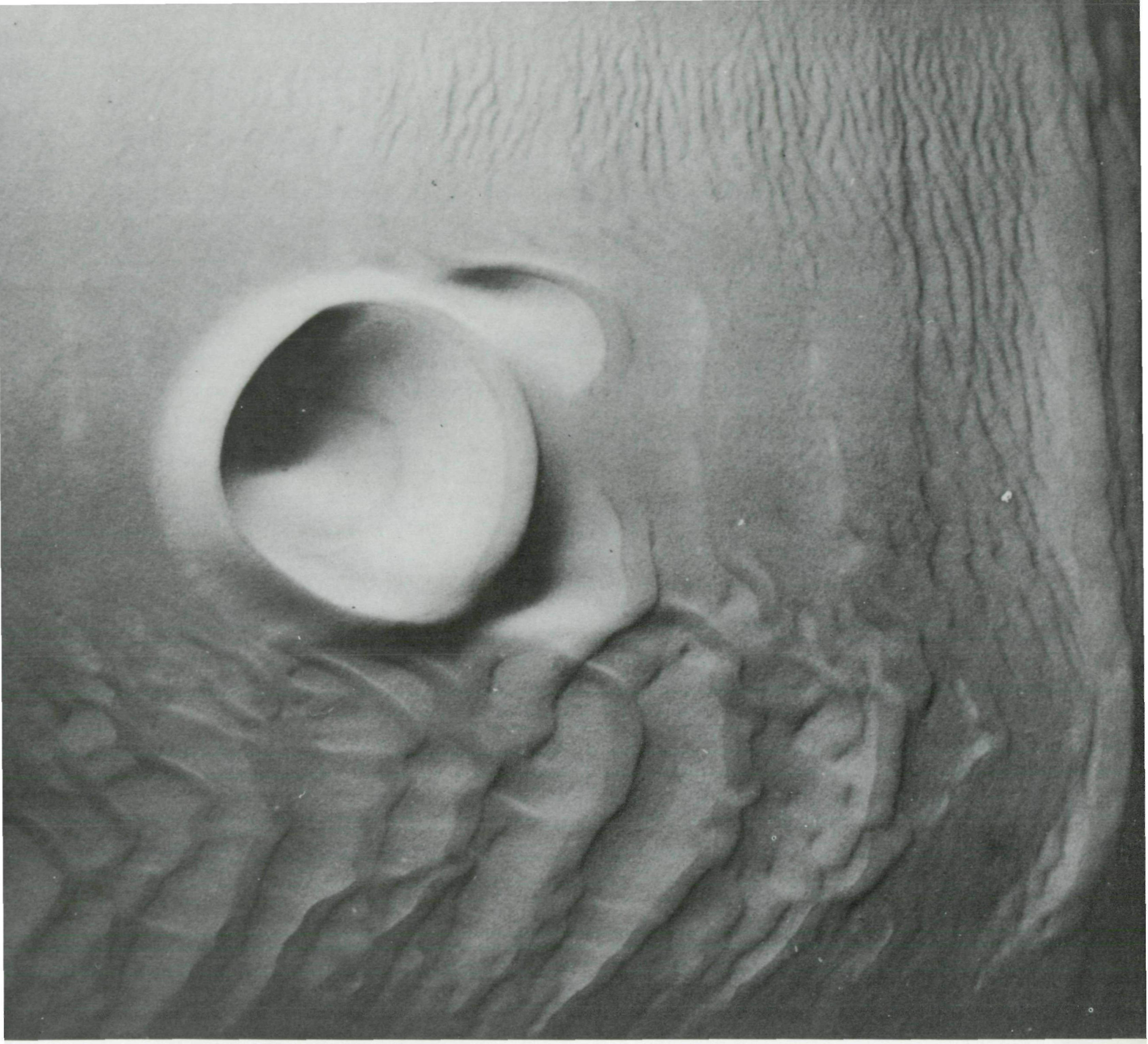




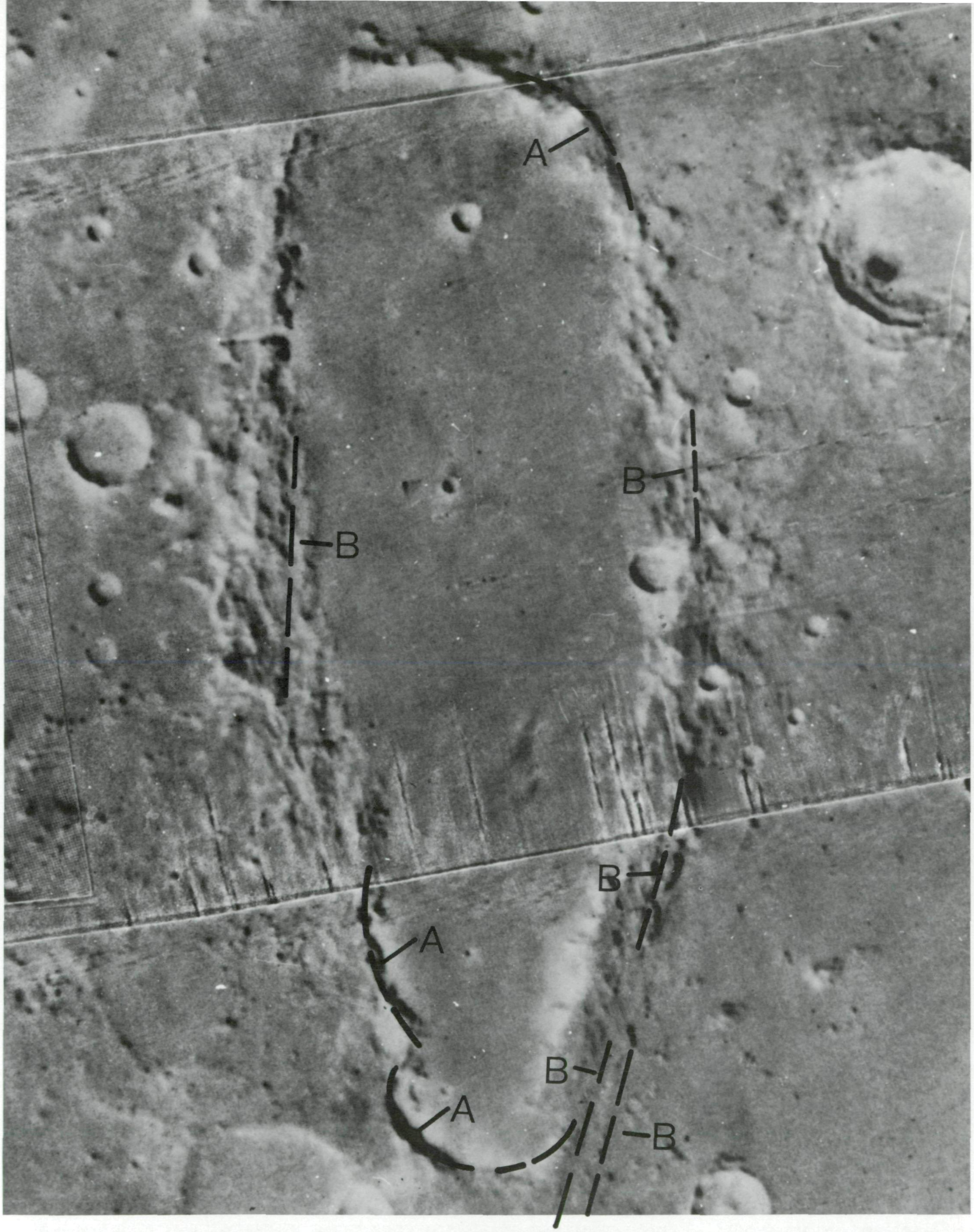
(9°N, 191°W; IPL 1947/173205)

A dark plume (left) extends more than 140 km downwind of this large crater in the Elysium Planitia. A laboratory simulation above, with the wind flowing from top to bottom, suggests that the dark martian plume may have been caused by wind erosion removing loose particulate material. Alternatively, the dark plume may be deposits of material originating from within the crater.—R. Greeley



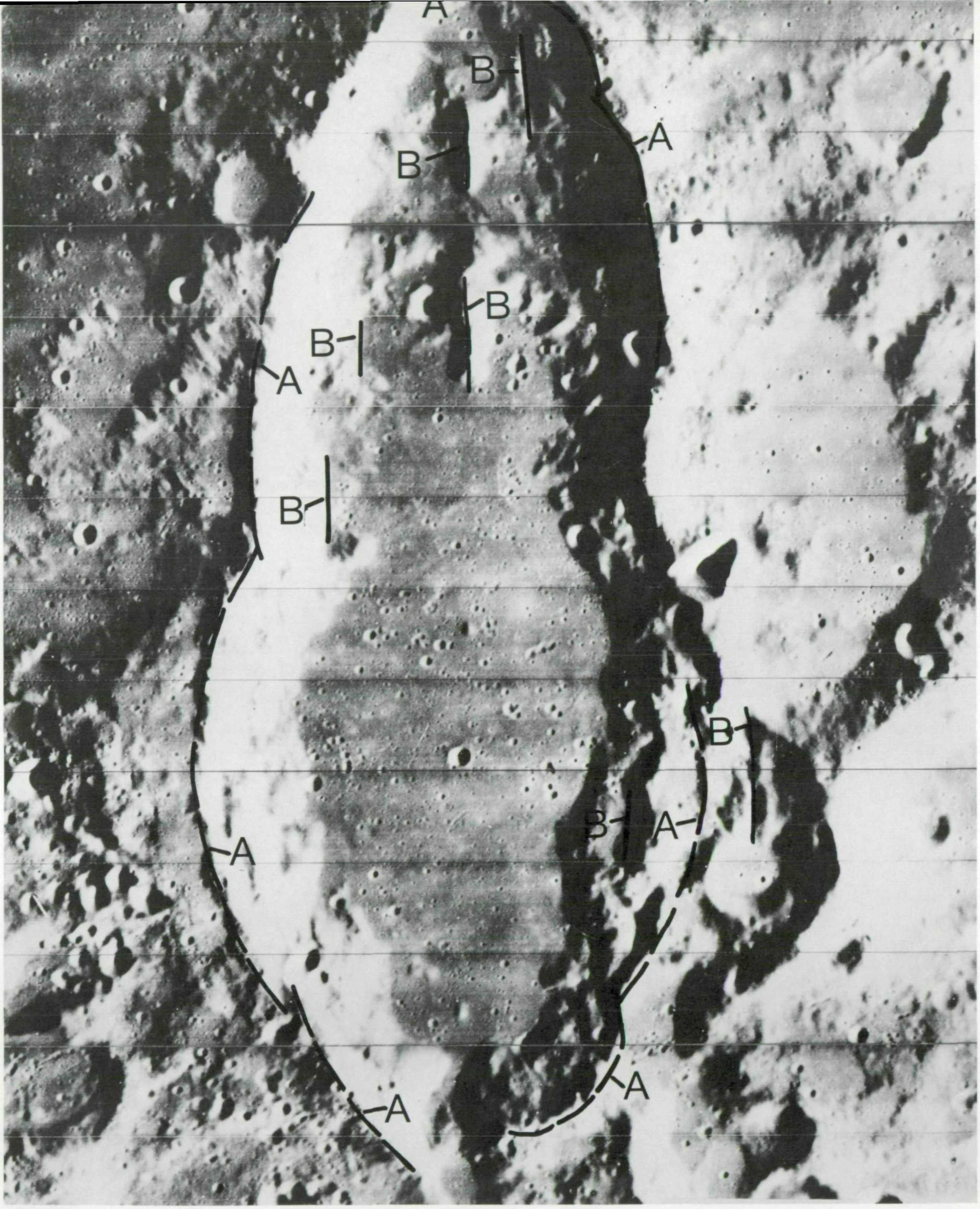


Wind-tunnel simulation examines effects of low-velocity wind flowing (left to right) past a raised-rim crater. Note the development of the blowout on the downwind flank of the crater. Such tests must consider wind velocity, crater geometry, threshold characteristics of surface material, scaling effects of size of crater, and effects of martian environment.—R. Greeley



(16°N, 182°W)

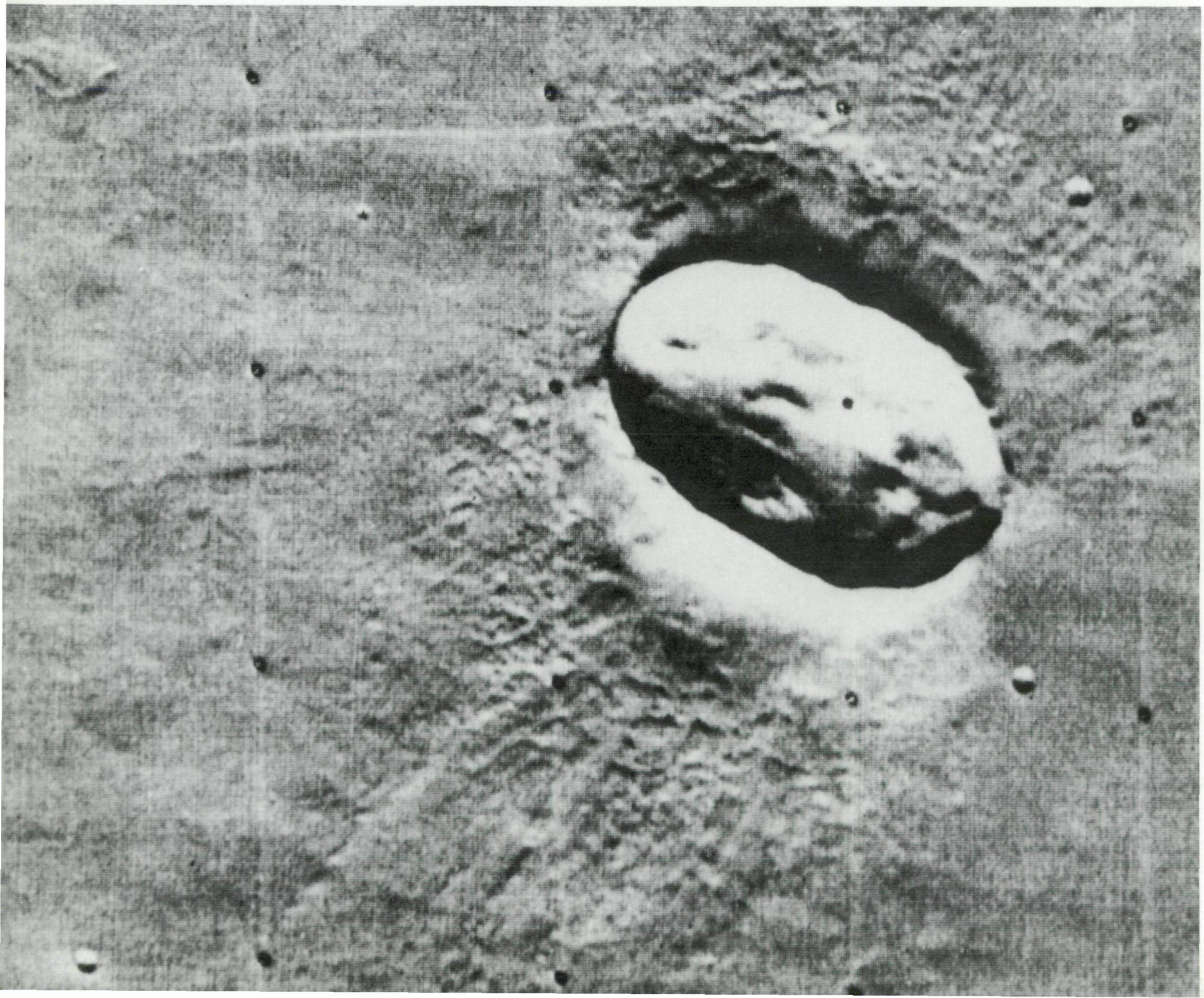
Very large, irregularly shaped craters exist on Mars (above) and on the Moon (right). The martian crater, Orcus Patera, is more than 400 km long; the lunar crater, Schiller, is about 180 km long. Craters of this shape and size are uncommon and their origins uncertain. Coalescing subcircular segments marked A suggest they may have

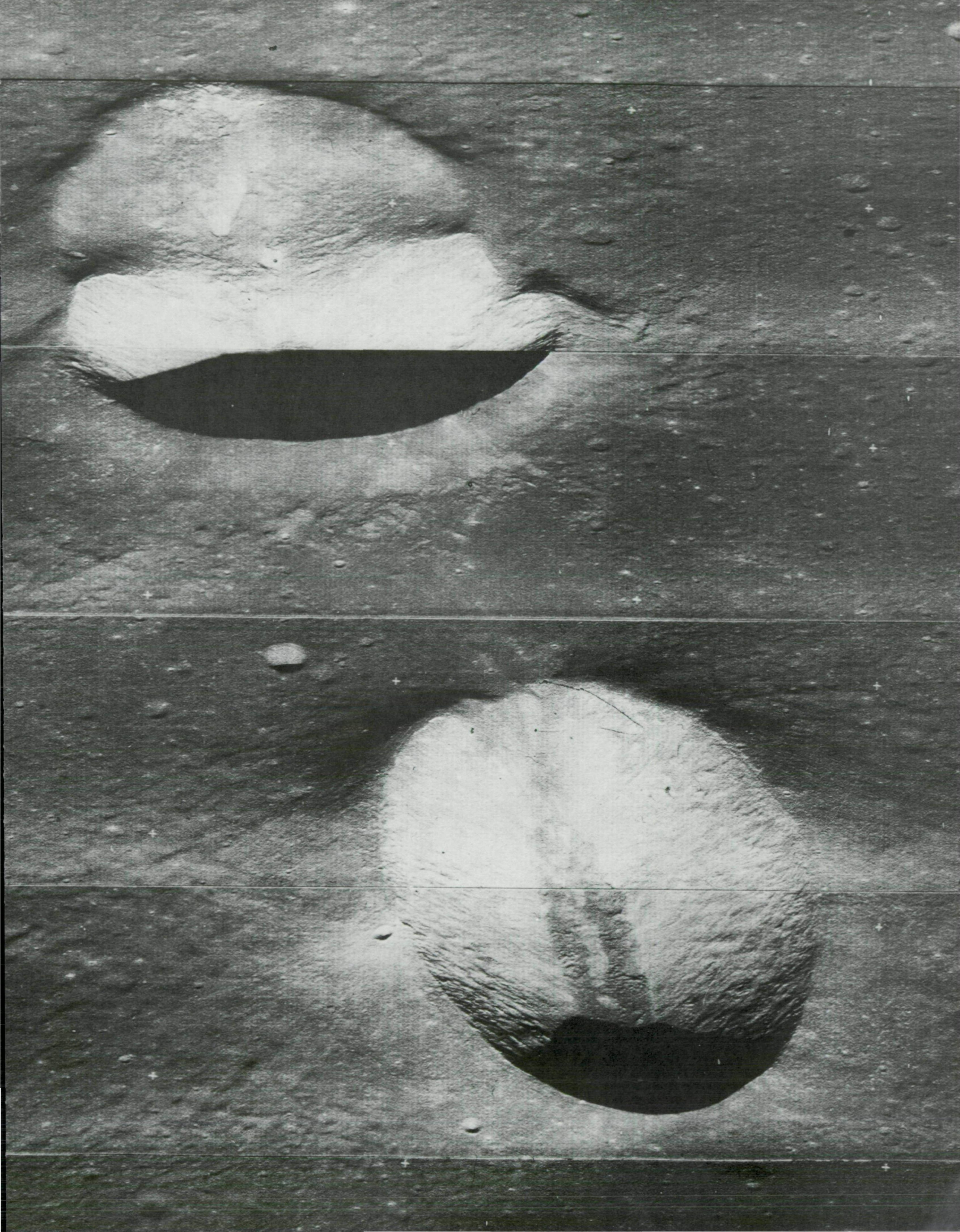


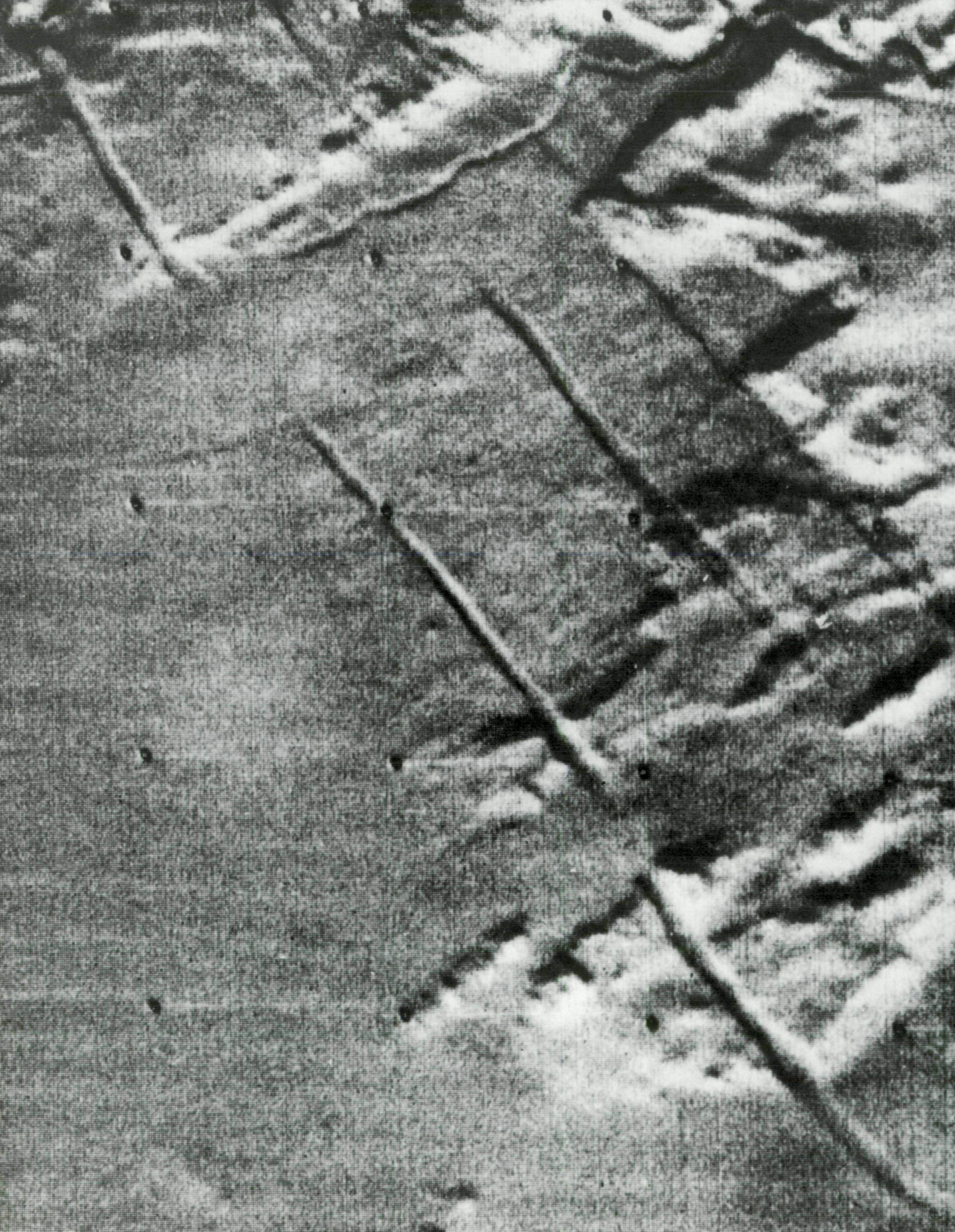
been formed by overlapping impacts or as volcanic features, but linear scarps and troughs marked B indicate a tectonic influence. Floors of both craters are flat and smooth. The martian crater is probably floored with wind-blown dust; the floor of Schiller may be covered by impact ejecta and volcanic flows.—D. H. Scott

(31°N, 220°W; IPL 1443/140643)

Highly elliptical craters on Mars and the Moon. Note that both the 12-km-long Messier A lunar crater (right, bottom) and the 15-km-long unnamed martian crater (below) have raised rims, linear structure on their floors, and ridge-like topography outside the long axis of the ellipse. While certain of these features have been interpreted as evidence for volcanic origin, laboratory studies have shown that the observed features can be reproduced in detail by low-angle meteorite impact.—N. W. Hinners

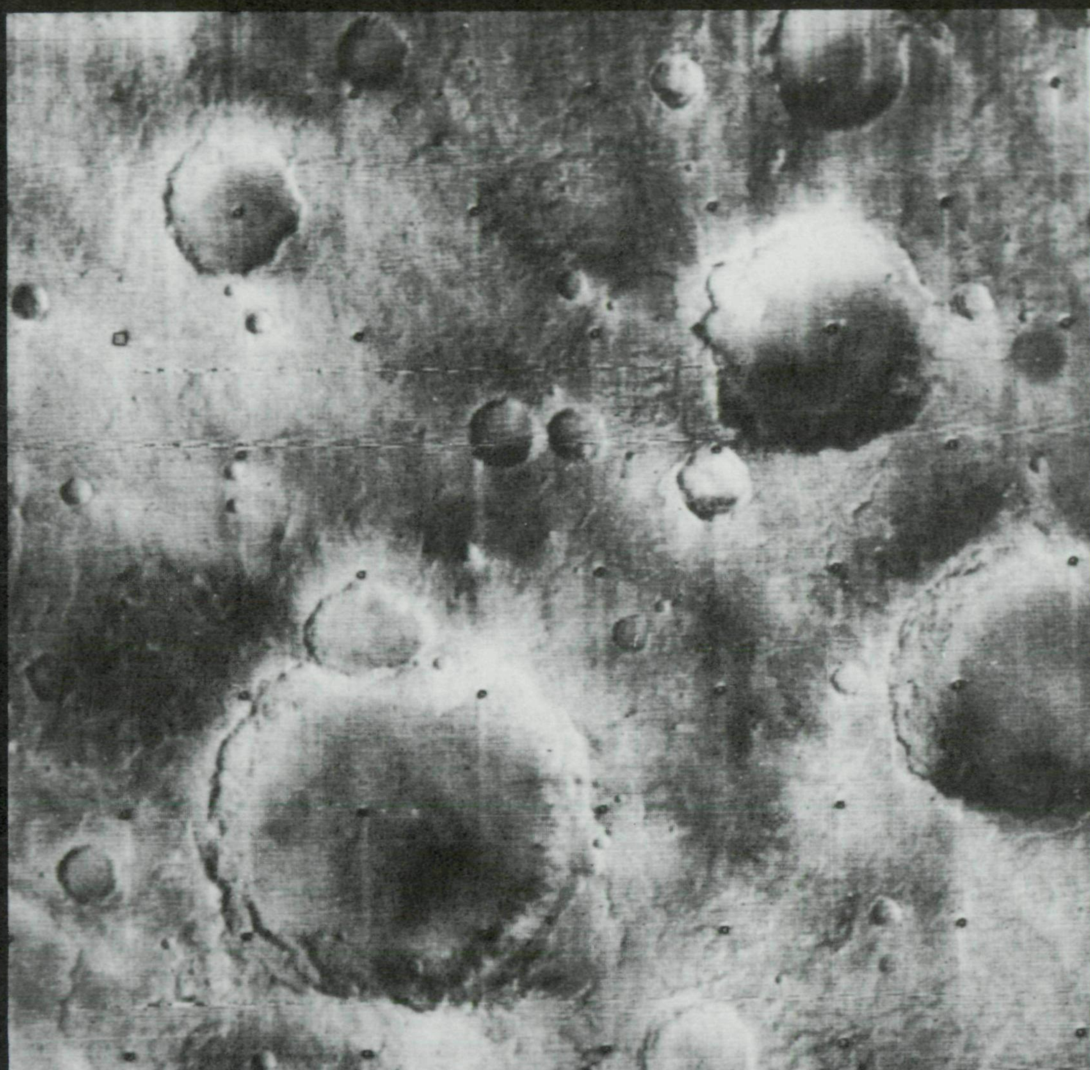






(13°N, 107°W; MTVS 4184–75)

Interrupted rilles appear both on Mars (left) and on the Moon. In each case low-elevation terrain adjoins high-elevation terrain, and both are transected in varying degree by rilles. Some of the martian rilles, such as those near the sinuous channel at upper left, may have been filled by deposition or sediment. Parts of the lunar rilles seem to have been somewhat filled by later lavas. Scale: the middle martian rille has an average width of 700 m; the largest lunar rille shown is about 2 km wide.—N. W. Hinners

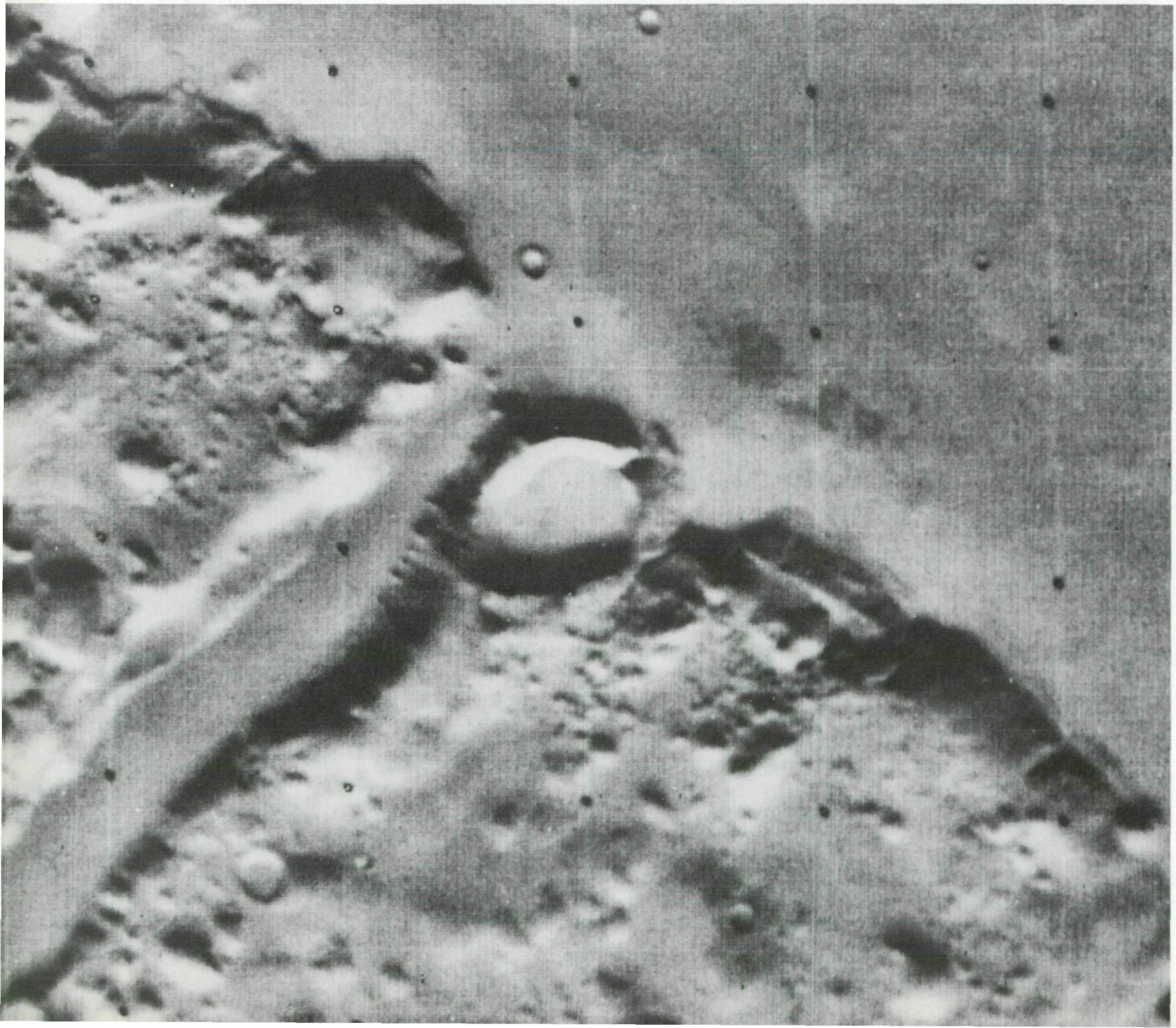


(23°S, 204°W; IPL 1642/1883351)

Heavily cratered terrain on Mars (above) bears striking resemblance to some areas on the Moon (right). One notable difference is that Mars does not appear to have as many smaller, bowl-shaped craters, which leads to the inference that, on Mars, they may have been eroded and filled.—N. W. Hinners

(31°N, 192°W; IPL 1449/223730)

Similar valleys on different worlds: a martian valley near Phlegra Montes (below) and Alpine Valley on the Moon (right). Both cut plateaus are studded with rugged peaks and the valley floors are filled by smooth plains materials. The Alpine Valley, 130 km long in the photo, belongs to a radial fault system in the Imbrium basin rim; the plains materials are post-basin mare basalts. The martian valley (photo width is 55 km) could also be a fault graben, but no relation to a basin has been discovered, and its origins are uncertain.—D. E. Wilhelms



Availability of Photographic Prints

Throughout this publication Mars imagery is identified by MTVS or IPL numbers except where mosaics are presented. These numbers represent the best processed image available.

NSSDC has Mars photos on file for the benefit of scientists engaged in the study of Mars. Inquiries (for MTVS or IPL numbers only) should be directed to

National Space Science Data Center
Goddard Space Flight Center
Code 601
Greenbelt, MD 20771

Information and price lists for general interest requests for any photo in this publication may be obtained from

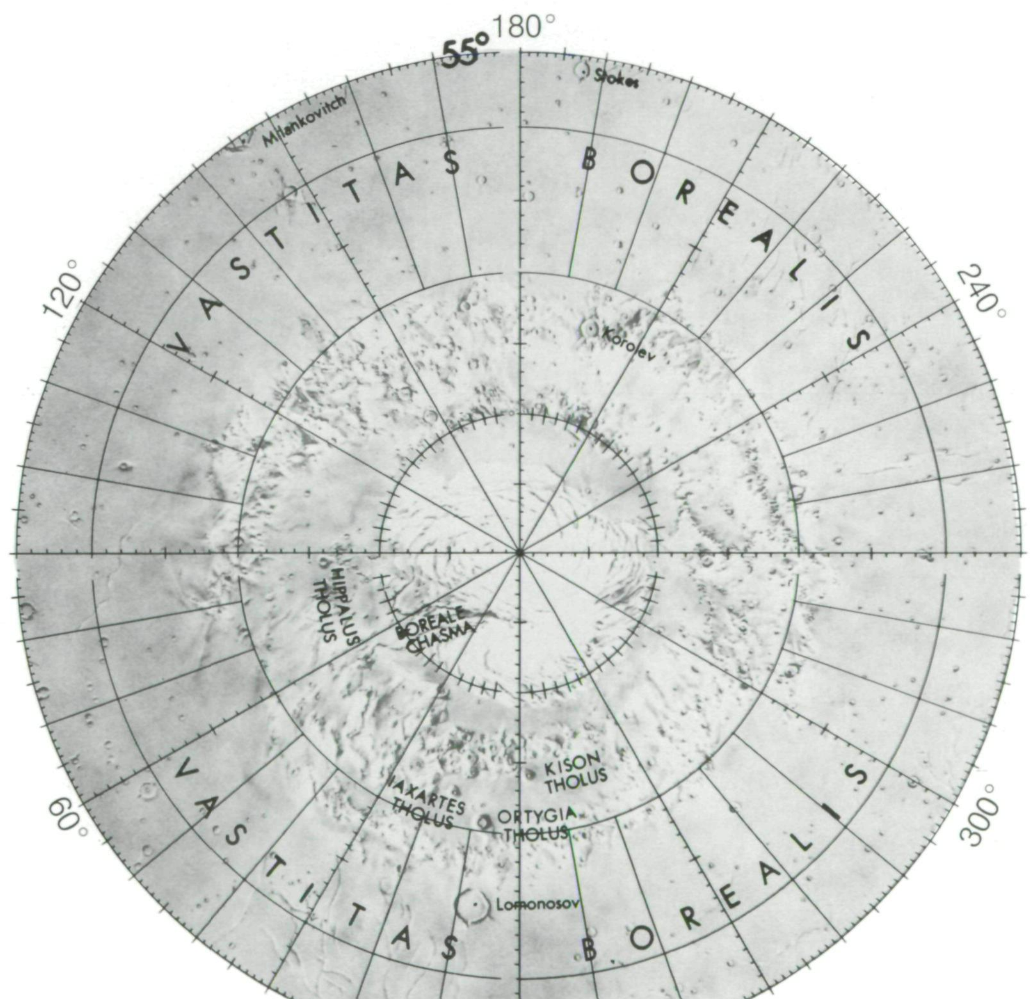
Bara Photographic, Inc.
Post Office Box 486
Bladensburg, MD 20710

Orders should include the publication number (NASA SP–329) and the page number (indicate "top" or "bottom" where necessary).

Polar Stereographic Projection

NORTH POLAR REGION

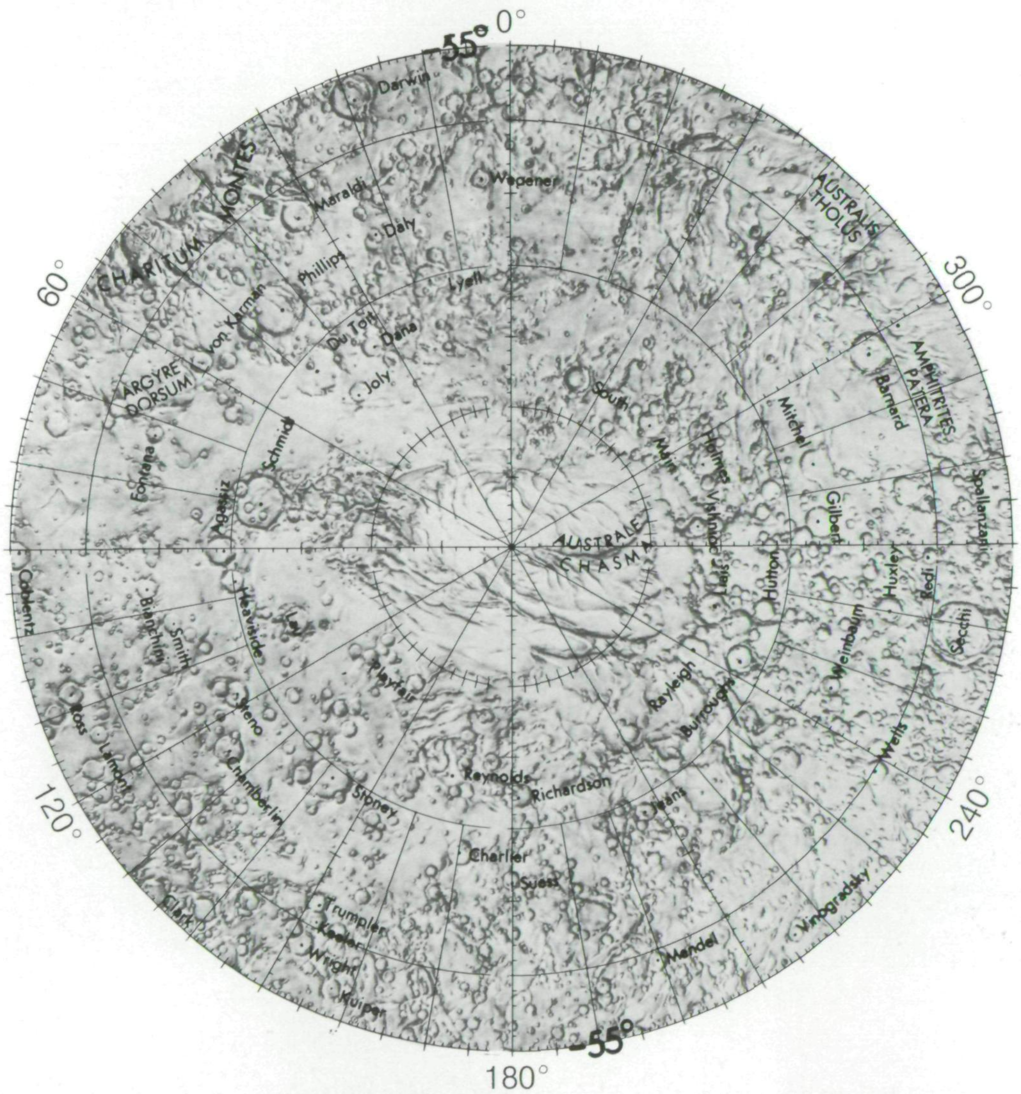
POLAR CAP AS IT APPEARED ON OCTOBER 12, 1972

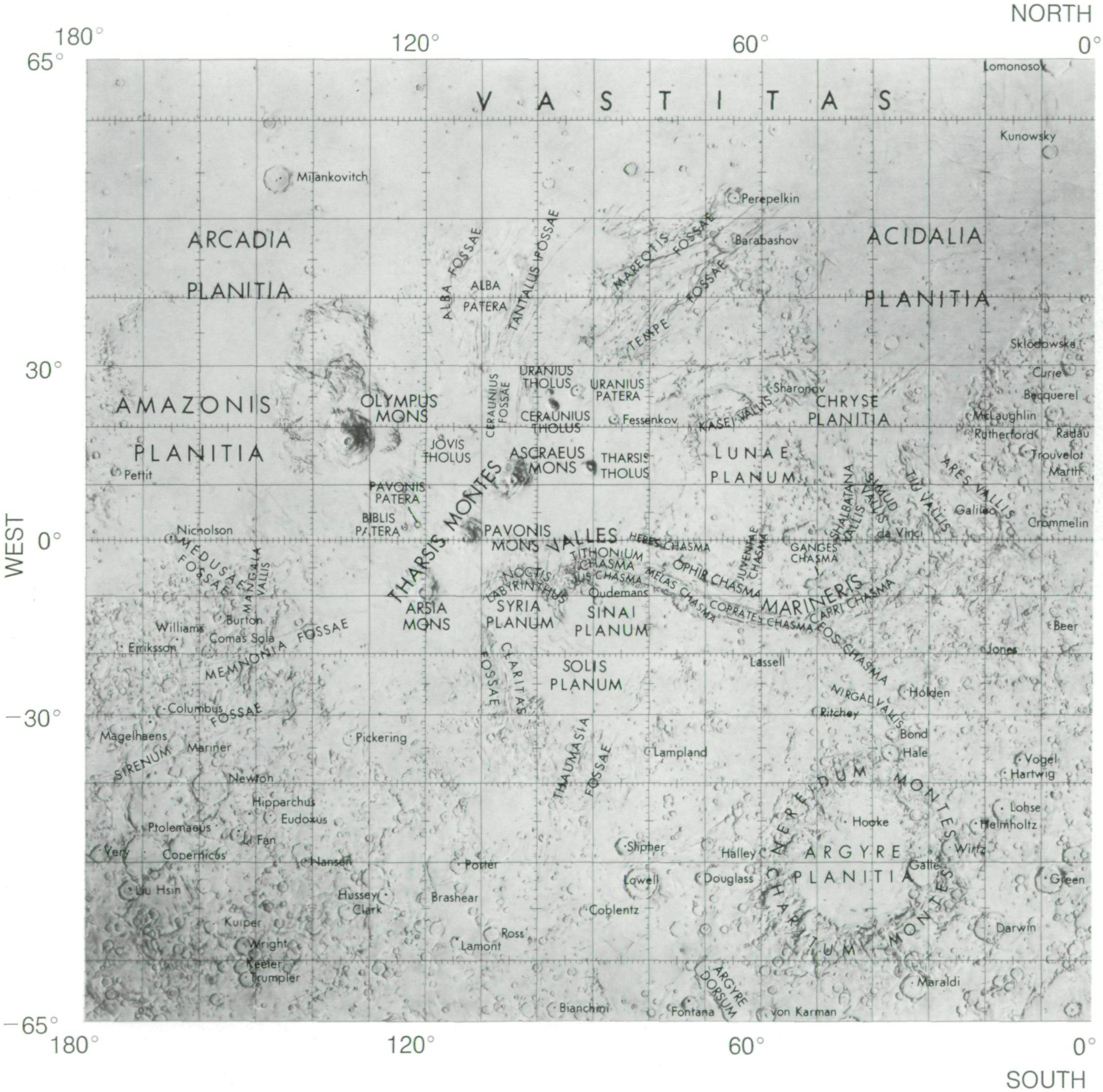


Shaded Relief Map of Mars

SOUTH POLAR REGION

POLAR CAP AS IT APPEARED ON FEBRUARY 28, 1972





U. S. Geological Survey, 1973. Topographic relief prepared from Mariner 9 television photography.

Mercator Projection